NOvA Update

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2005 Aspen PAC Meeting

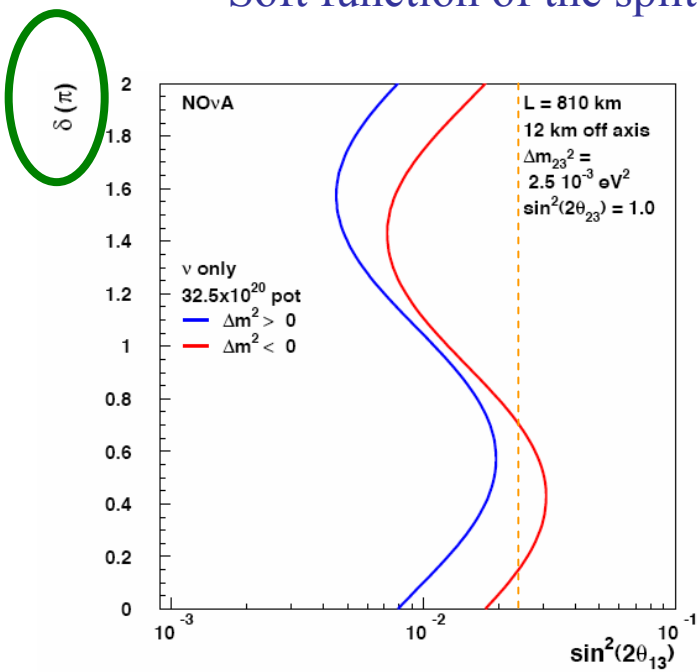
Topics

- What happened at NuSAG
- Response to PAC Questions
- Collaboration Building
- Project team building

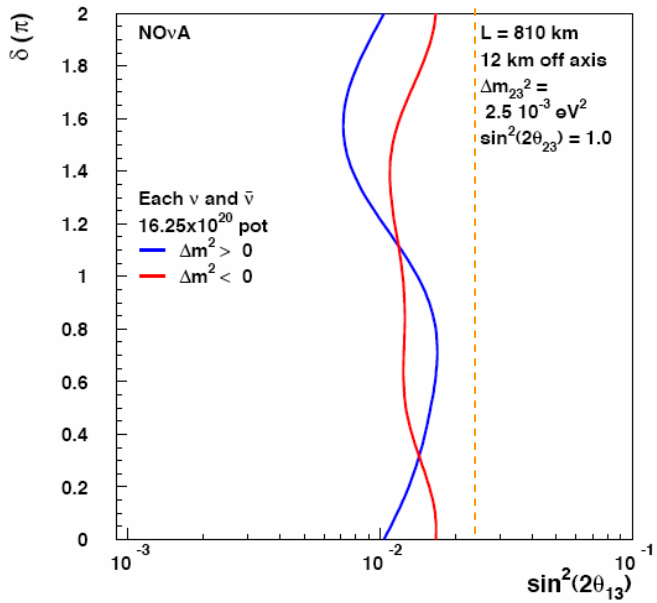
EPP2010, NuSAG,…

NOνA plots change slightly & a new style developed

- First, we have been showing 5 years of NOνA ν running compared to "medium" reactor experiments
- But in fact we do better on $\sin^2(2\theta_{13})$ if we run
  2.5 years ν and 2.5 years anti-ν
  - Soft function of the split between ν and anti-ν



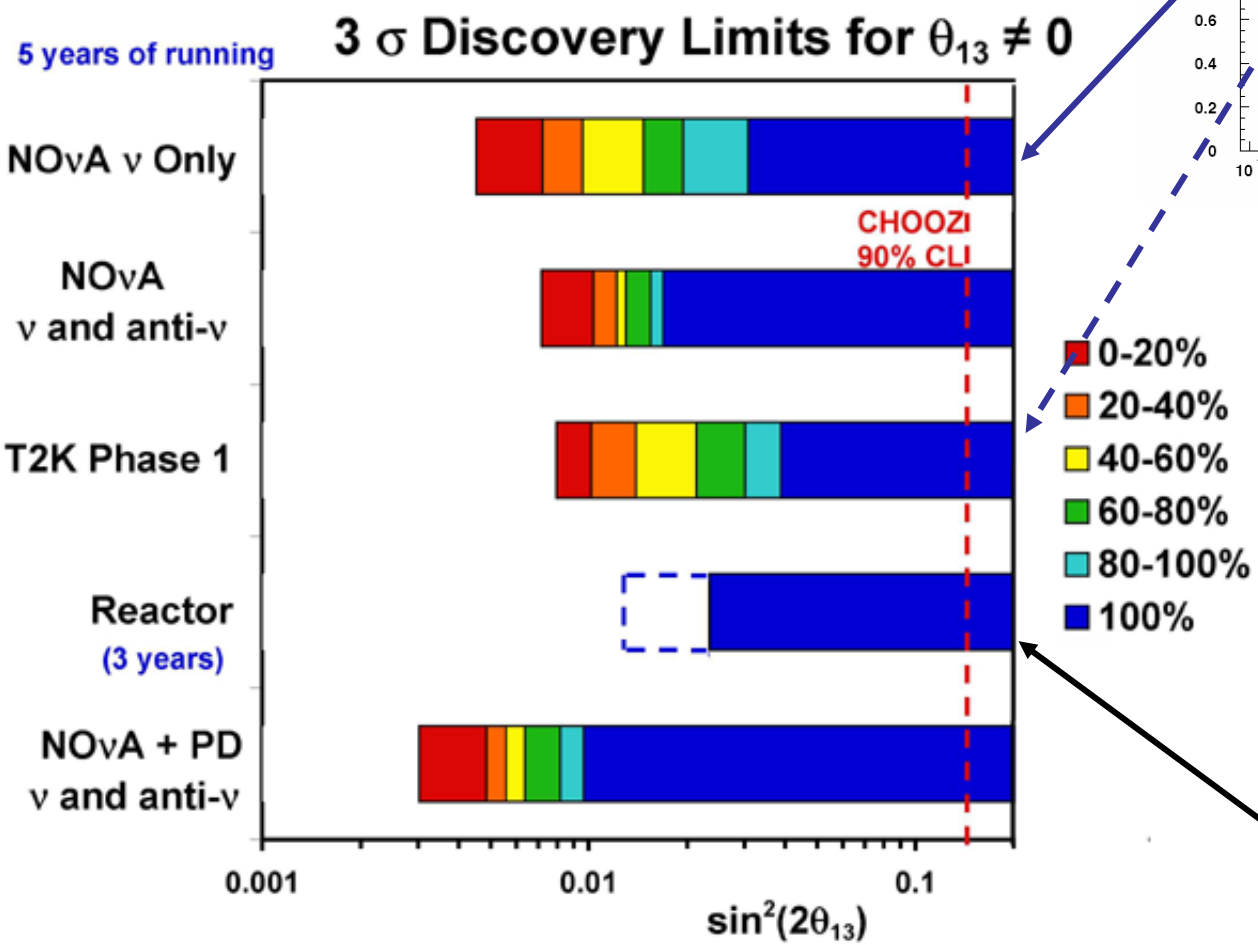
5 year ν only run

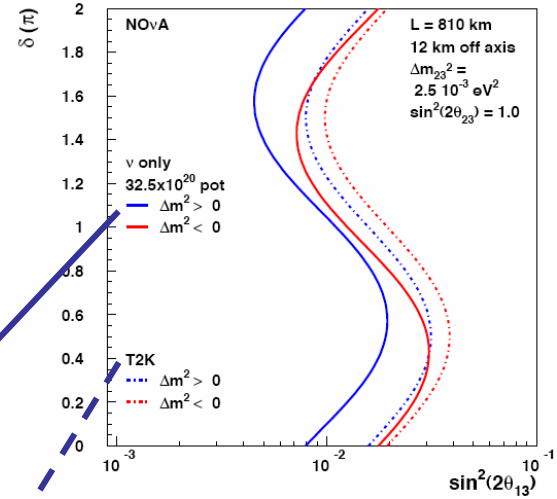


2.5 yr each ν and ν̄ run

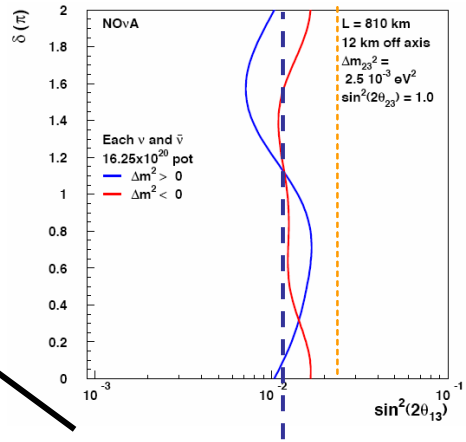
New bar charts

- Instead of fraction of δ





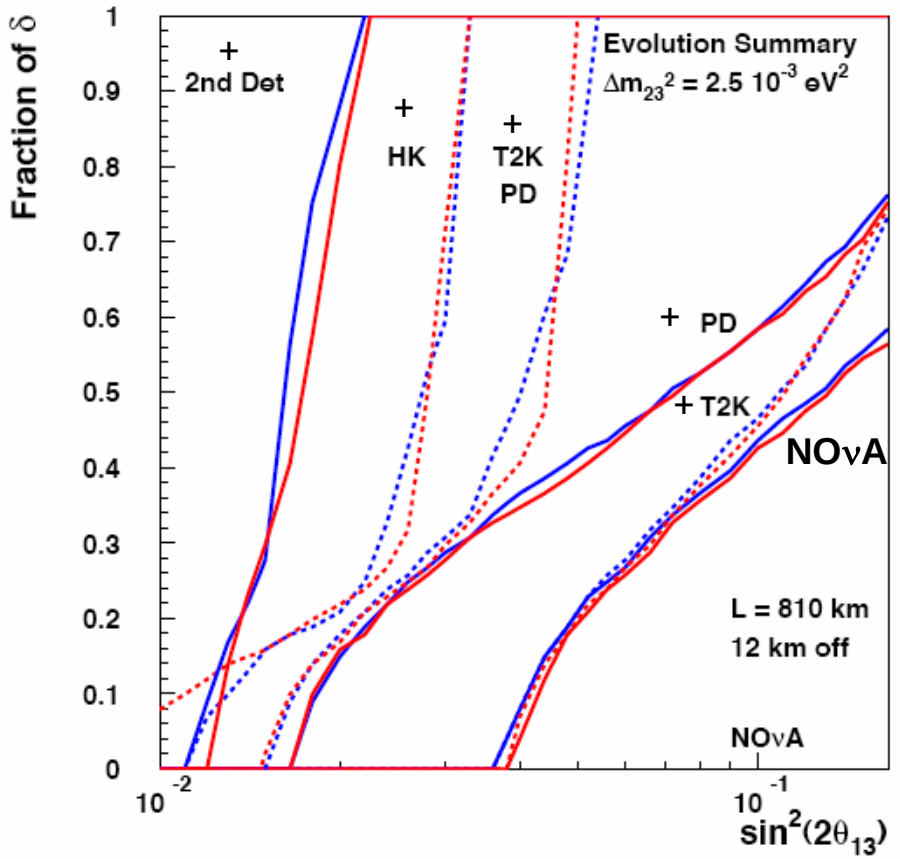
5 year ν only run

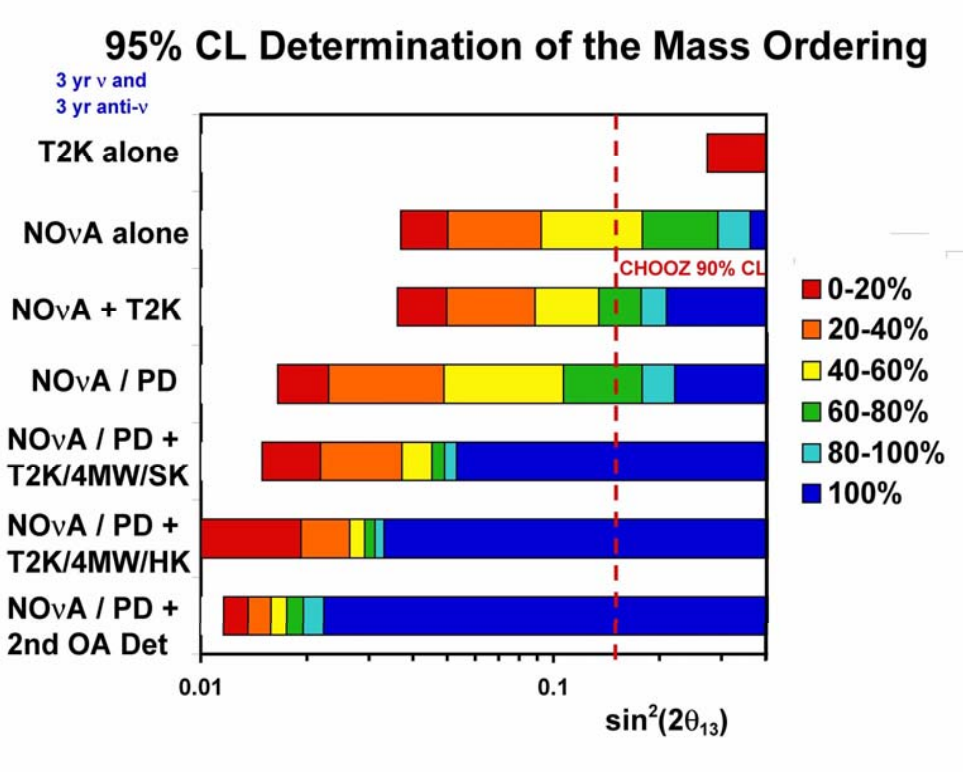


2.5 yr each ν and ν̄ run

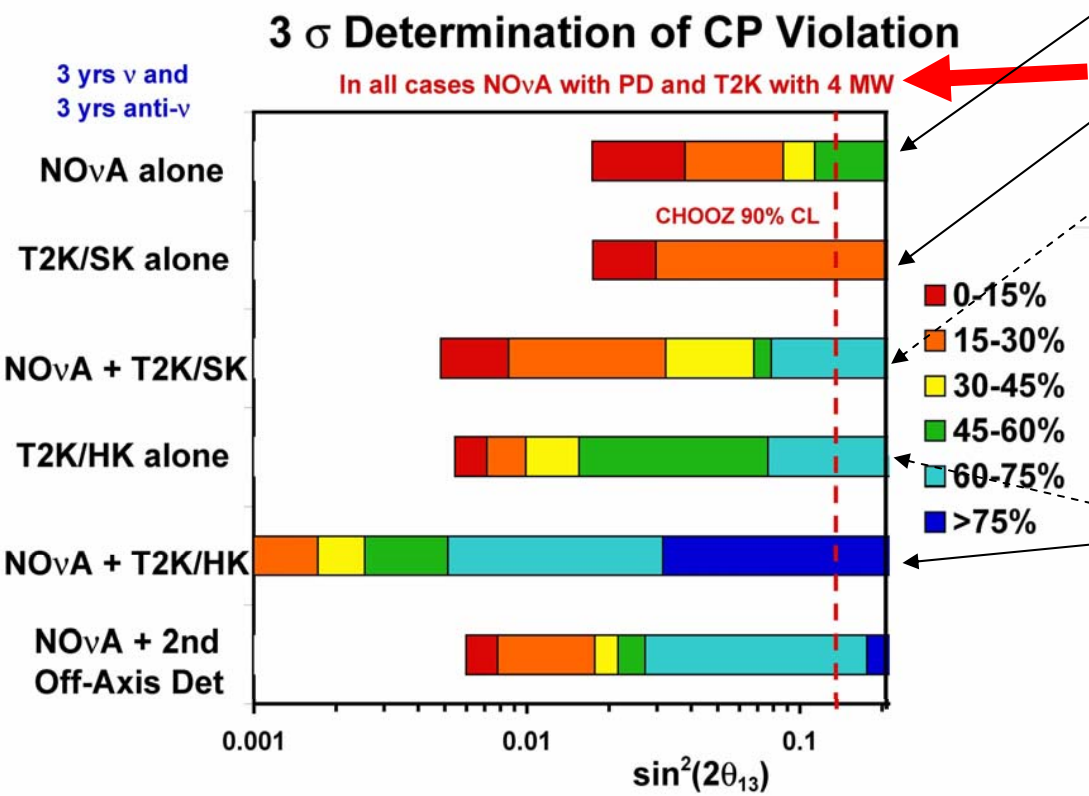
Braidwood at NuSAG said to be 2 times better than "medium"

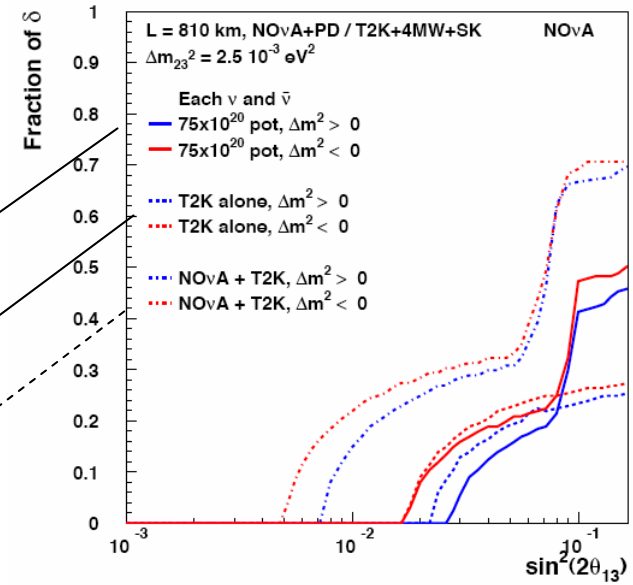
New Bar chart for Mass Hierarchy

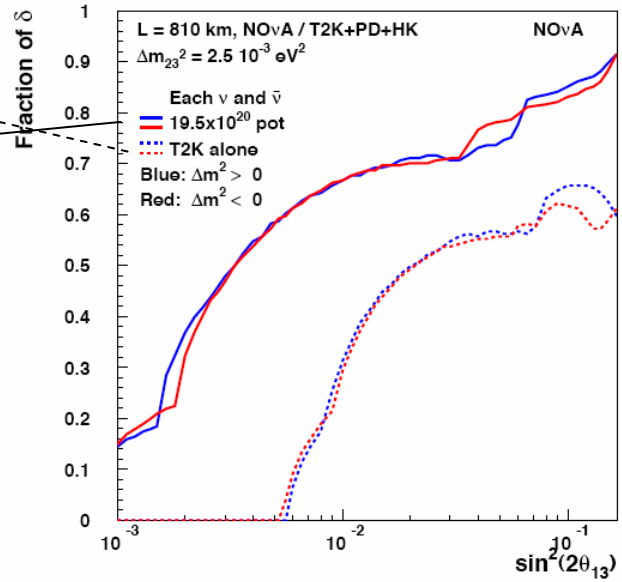




New Bar chart for CP



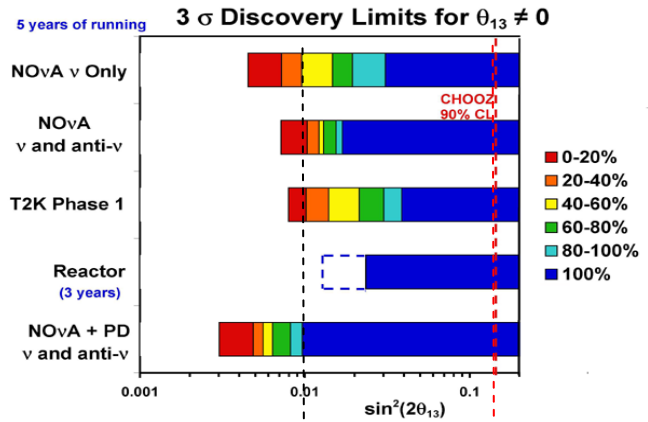




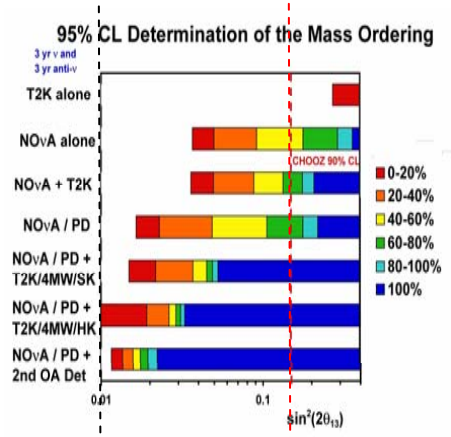
Bar charts illustrate how each problem is harder than the last for

$0.01 < \sin^2(2\theta_{13}) < 0.14$

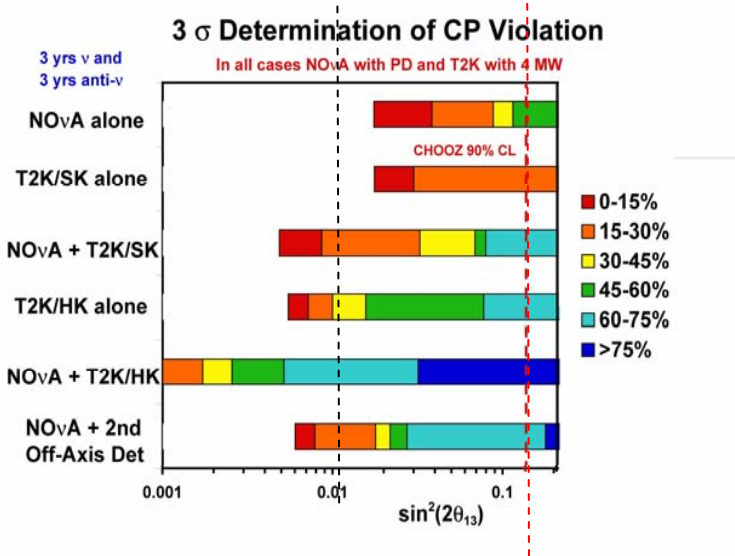
Lots of blue



Some blue with combinations of experiments (4MW to get all the way)



No 100% blue at all (some values Don't have CP violation)



8 PAC Questions from April 2005

Question #1:

How might a future program of NOνA evolve in the absence of a Proton Driver at Fermilab?

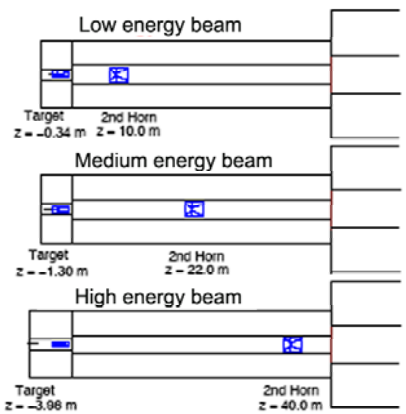
- The Proton Driver in the NOνA proposal / figures is a factor of 25.2 / 6.5 = 3.88 (per year)
  - If there is no PD, there are still accelerator upgrades one could do
- The Accelerator Division has a "Proton Study Group" chaired by Mike Syphers looking at the entire complex
  - Recycler work is required for the 6.5 x 10^{20} per year assumption pre-PD and this group will study that.
  - But the Linac, Booster, Debuncher, and Accumulator also might be employed
  - Main Injector RF is in the NOνA proposal as part of the PD upgrade,
    - This is a factor of ~ 1.5 by itself
    - We noted in our proposal that this RF upgrade could be done even if a PD was not done

Question #1:

- A future program could build more mass
  - Note a factor of 2.6 in mass coupled with the factor 1.47 from a MI RF upgrade = Proton Driver.
- A future program could just run longer
  - No additional mass, but 2.6 x as long also = Proton Driver
  - Yeah, but that's 13 years! Could happen…..
- A future program depends on what we find in this first step
  Remember this is an incremental program
  - e.g. a large value of $\sin^2(2\theta_{13})$ could allow us to relax cuts against backgrounds & increase the signal at the 1st maximum?
    - Remember colliders "top via eμ only" eventually became all possible signal channels and all contributed to the top mass measurement.
  - e.g. if $\sin^2(2\theta_{13})$ is large, then a 2nd detector at the 2nd oscillation maximum could make sense without a PD?
    - tough, fighting factor of 30 reduction in flux, so it's probably a bigger 2nd detector than the 50 kt in the proposal? See proposal figure 13.15.

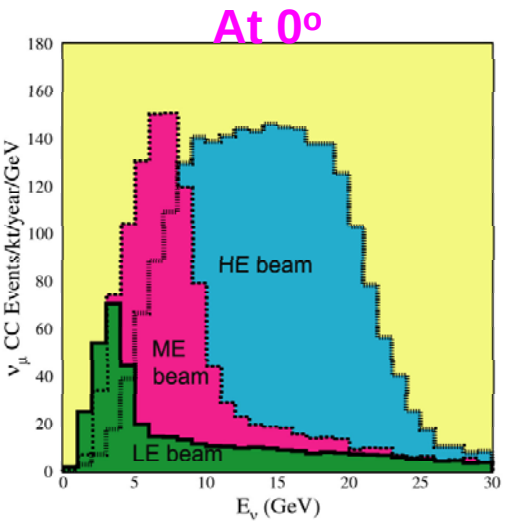
Question #1:

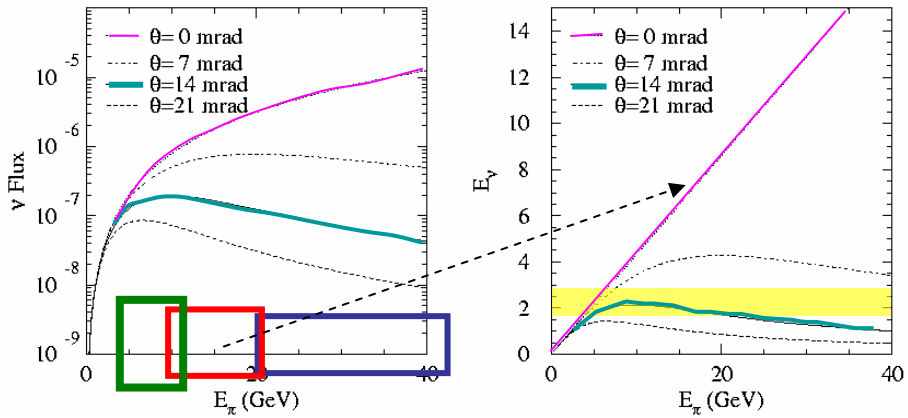
- Could we better optimize the NuMI beam for 2 GeV neutrino production at 14.8 mrad?

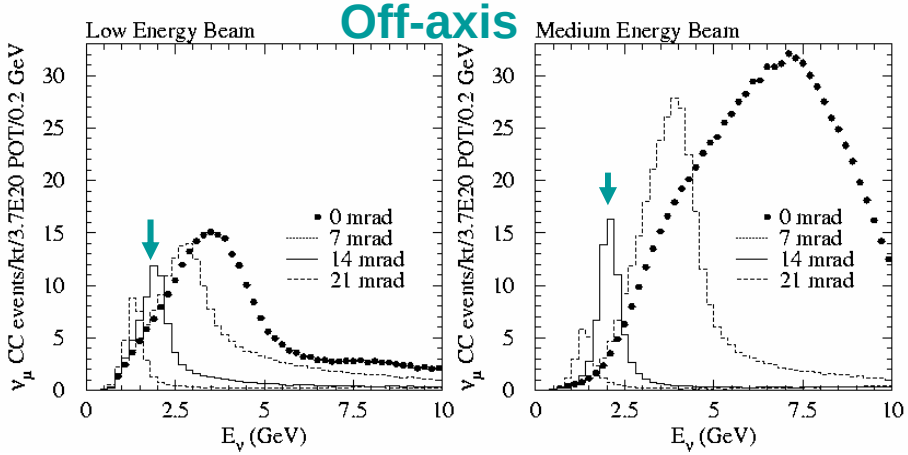


←Target

2nd Horn ⟶







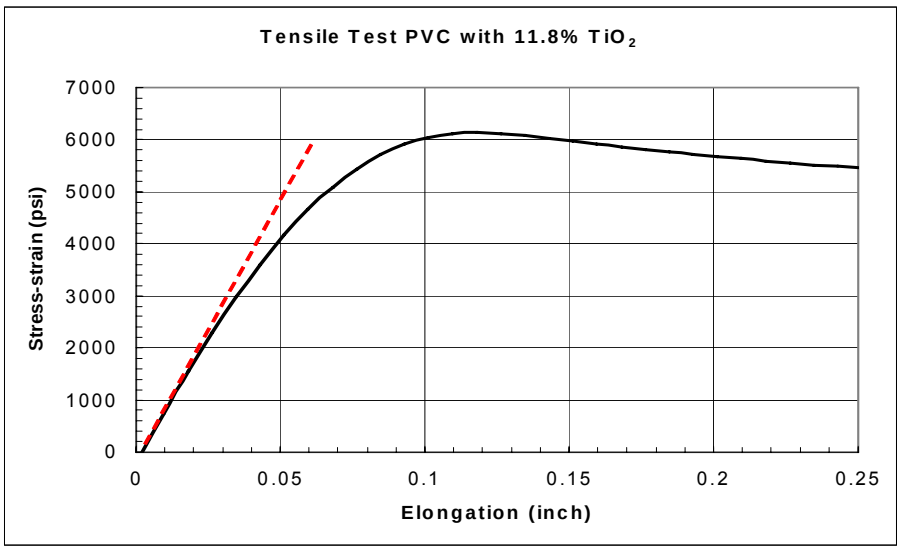
- There may be 10%-ish gains from tuning the "medium" energy?

Question #2: NOvA is a large, novel structure.

a) Mechanical prototype?
b) ES&H concerns?
c) Required approvals: schedule/ cost impact?

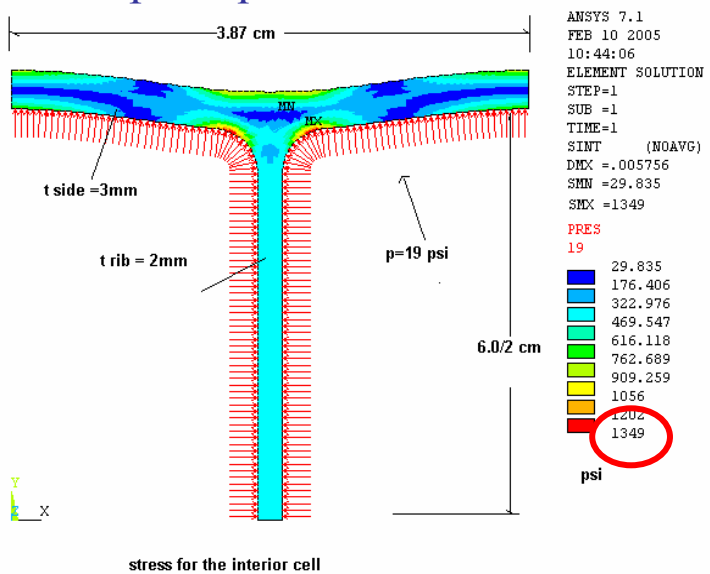
- **First, an update on the large, novel structure.**
  - We continue to iterate the PVC design to lower the stress and risk.
  - Recall our problem is that PVC is "plastic" and can suffer creep stress
  - We have tried to constrain the design to hold all stresses < 1500 psi.

- **Strength of Material**



PVC cell properties

With 19 psi liquid inside & a 1/8" corner radius



stress for the interior cell

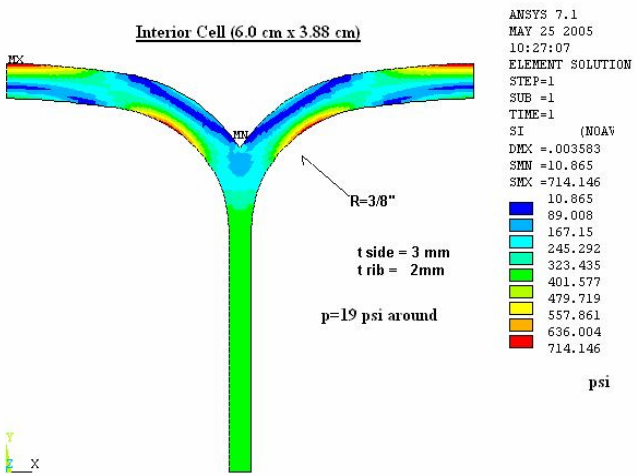
The cell design can be improved -1

- A scalloped cell with a large radius of curvature at the corners reduces stress **from 1350 psi** (1/8" radius)

To 714 psi
if change to 3/8" radius

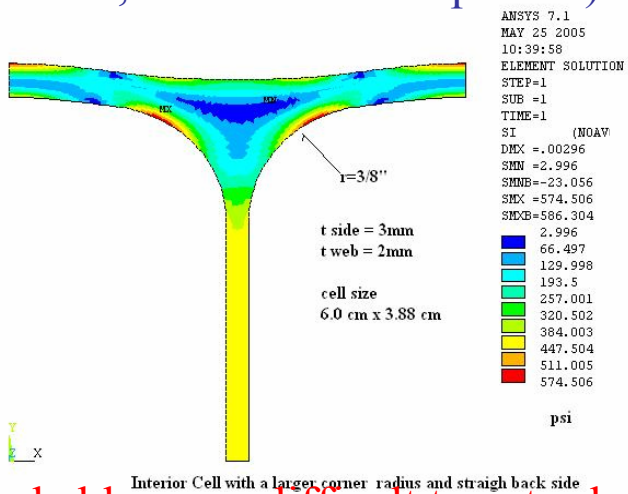
To 574 psi
if filled in
(means 15% more PVC mass, less active, non-uniform response?)

To 571 psi
with a pocket hole
(means 7% more PVC mass, less active)



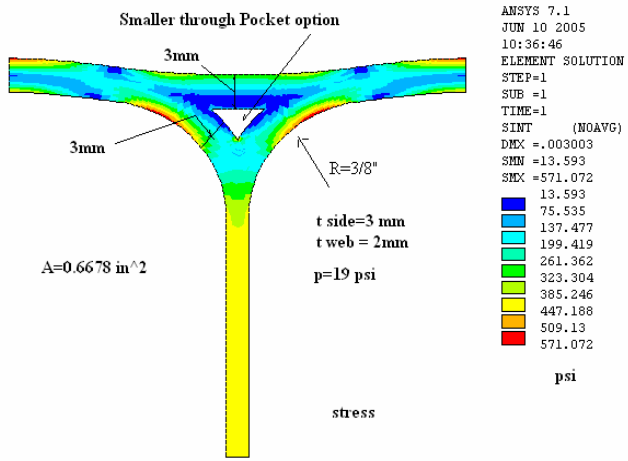
Probably easy to extrude since uniform walls

But lose 3% of liquid mass



Interior Cell with a larger corner radius and straigh back side

Probably more difficult to extrude since more mass at this tee, cooling problem



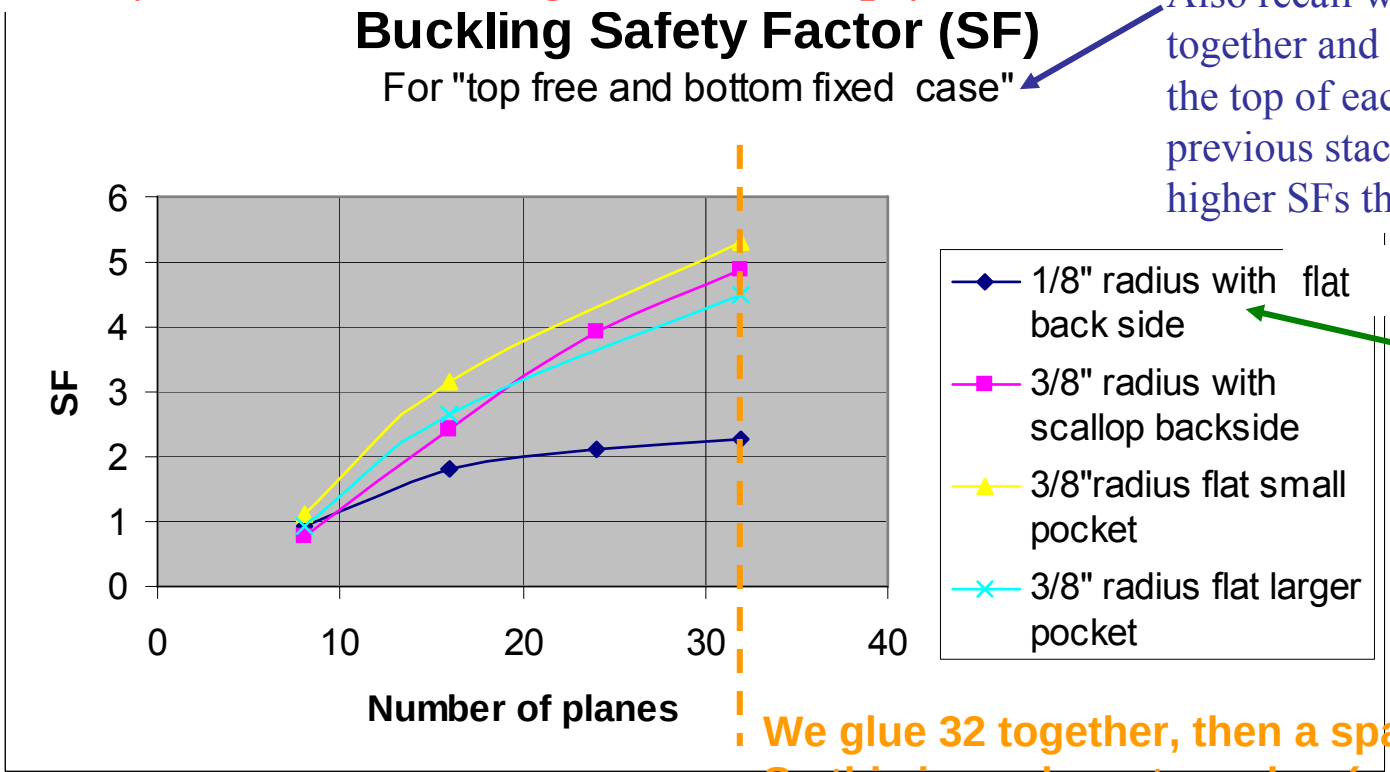
Interior Cell with a 3/8" radius & pocket flat backside

Extrudable?

The cell design can be improved -2

- These scalloped cell shapes also give a larger safety factor on buckling of a vertical set of N planes
  - **Approaching round tubes**

This FEA is for planes full of liquid,
Safety factors are 6x higher when empty



Also recall we glue sets of 8 together and also glue the top of each 8 to the previous stack, so we get higher SFs than shown here

Proposal case

We glue 32 together, then a spacer, So this is a relevant number (eventually)

The cell design can be improved -3

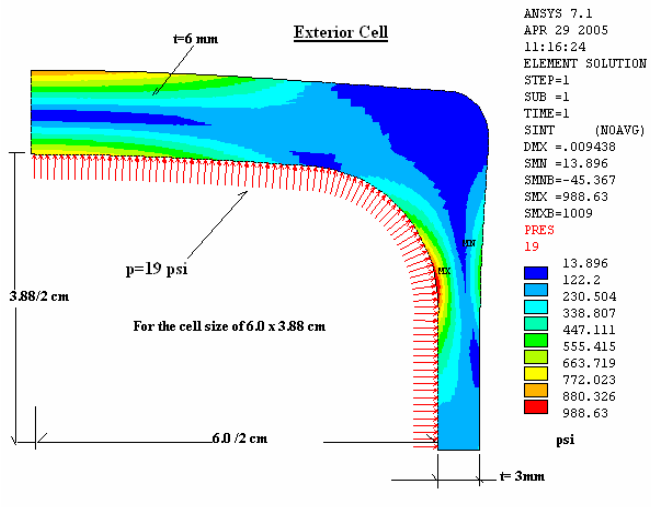
- The outside end of a 32-cell extrusion of 4 cm by 6 cm cells requires a beefier wall to hold the 19 psi pressure of scintillator inside
  - Just the outside edges, not in the interior of NOvA
  - Since it spans 6.0 cm along the beam direction under this pressure
    vs. the typical interior cell span of only 4 cm transverse to the beam
  - That is, this "outside web wall" has to be thicker (if flat, 6mm PVC instead of only 3mm)

Flat outside wall

6mm PVC, 3/8" radius

988 psi max stress

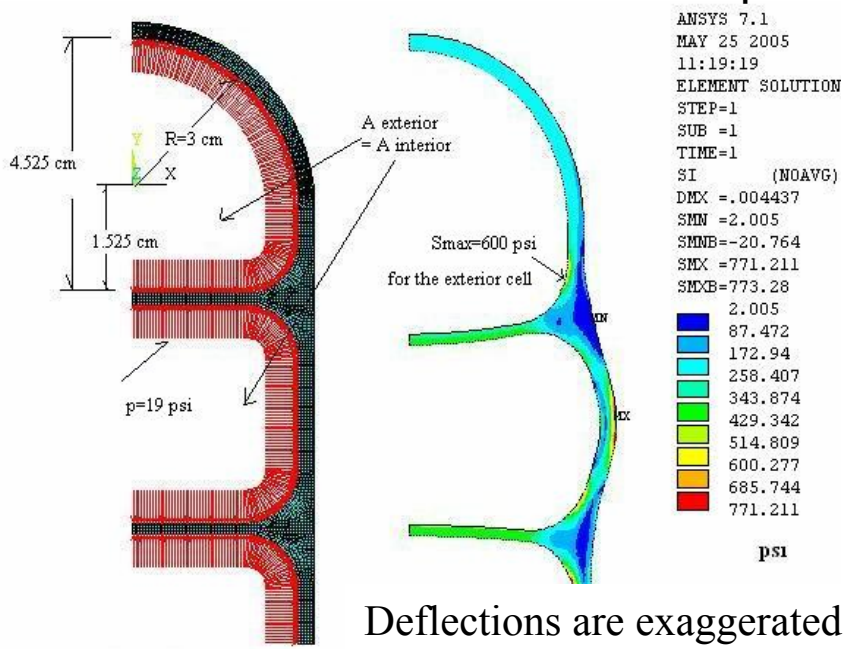
(1/8" radius gave 1875 psi)



Circular outside wall

Gets back to 3mm PVC

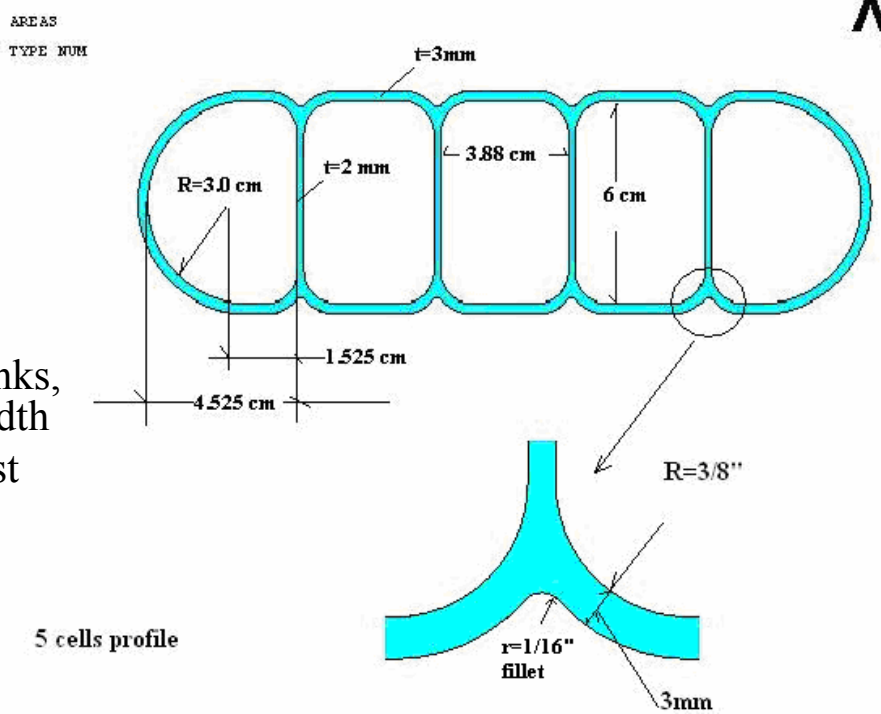
AND reduces max stress to 771 psi



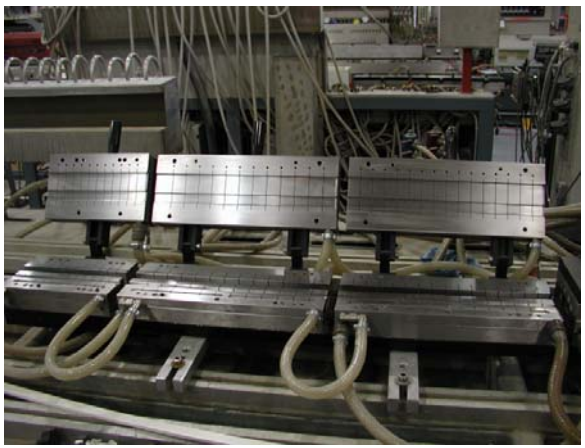
Deflections are exaggerated

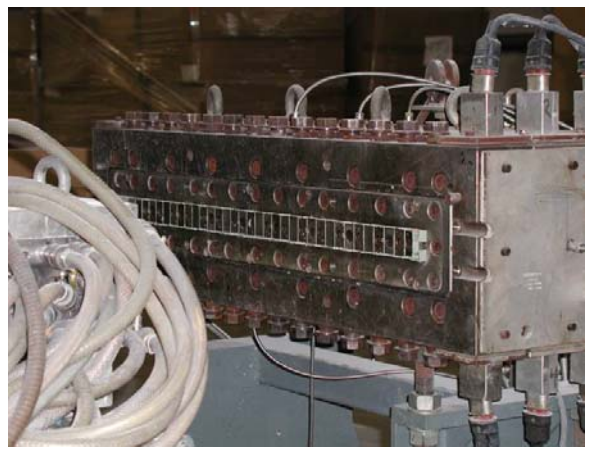
The cell design can be improved - 4

- **We are approaching a more organic shape?**
- **All the above points mean we need to take additional R&D steps before we have a final extrusion to test in any full size prototype**
  - The 32-cell die will cost perhaps $ 250 - 300 K
  - It looks like a 16-cell die will be ~ $ 180 K
    - Existing vendors have appropriate cooling tanks, pullers, and traveling cut-off saws for this width
  - A 3 or 5 cell die seems to be in the rather wide cost range of $10 - 80 K ???
  - These are complicated multipart dies



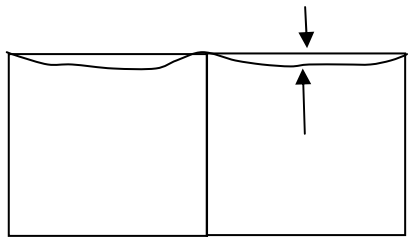
5 cells profile





The cell design can be improved - 5

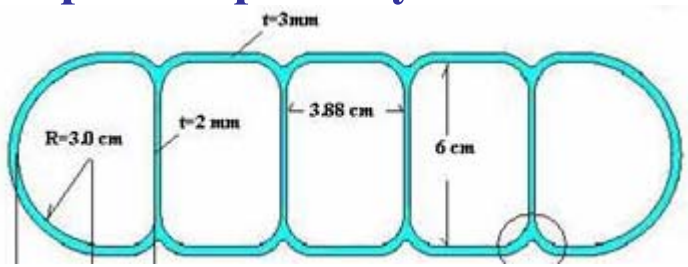
- These scalloped cell shapes also impact how we would glue one plane to another
  - **One existing example of the T-shape has dips between the webs:**



20 mil dips seen, epoxy fills dips

This is with a very thin wall extrusion, about 50% of our design thickness

  - **The scalloped shapes may force a better contact**



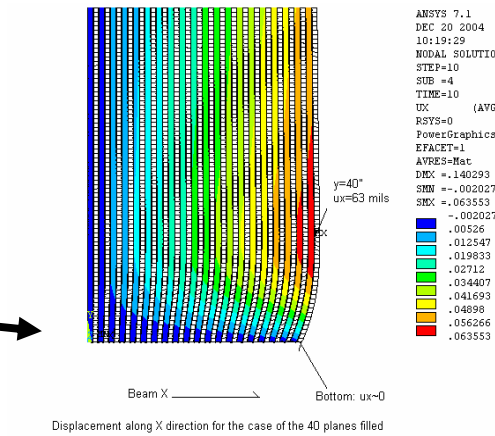
  - **But scallops could make parts difficult to handle via vacuum fixtures as planned?**
  - **And will also require more precise epoxy placement**
    - **And viscosity**

Back to the Question #2:

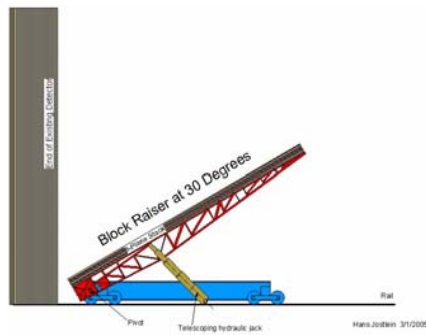
NOνA is a large, novel structure.

a) Mechanical prototype?

- **We have looked at <u>where</u> we might build a full mechanical prototype**
  - **It would be ~ 53 ft tall, but maybe not the full 53 ft width?**
    - Argonne maximum building is 40 ft
    - Fermilab has
      - 39 ft Wide Band
      - 44 ft New Muon
      - 52.5 ft CDF
      - 60 ft DZero in pit & the pit is > 60 ft wide so could assemble a tall object
- **What would be the purpose?**
  - **Recall the plastic grows in displacement along the beam direction when we fill it with scintillator**
    - Could study this with a **<u>short</u>** device if we pressurize it
    - Still need 40 – 60 planes deep to see the effect and verify the FEA
  - **Full height may only be needed for buckling stability tests**
    - Perhaps 2 m wide, probably only 8 planes deep, so easier
- **A test assembly is yet another problem, we will not have the Block Raiser until later**



Displacement along X direction for the case of the 40 planes filled



Back to the Question #2:

NOνA is a large, novel structure.

b) ES&H concerns on structure?

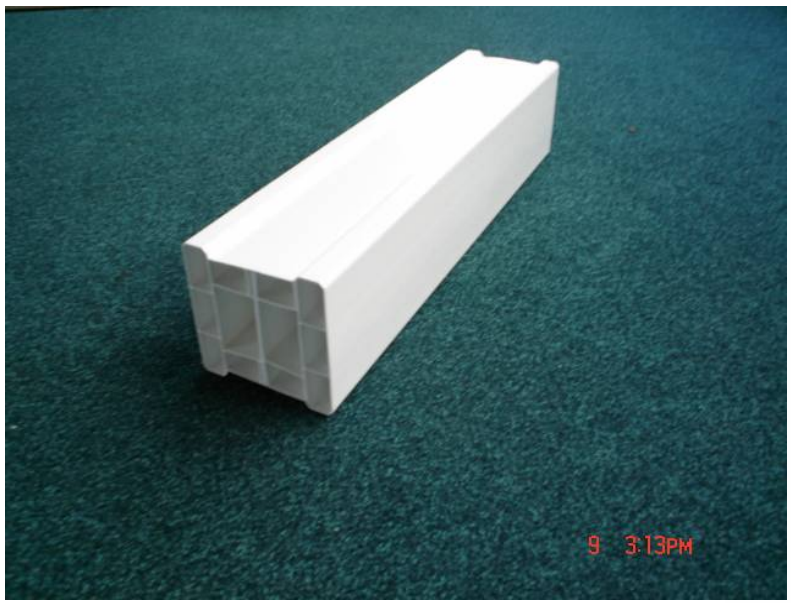
c) Required structure approvals: schedule/ cost impact?

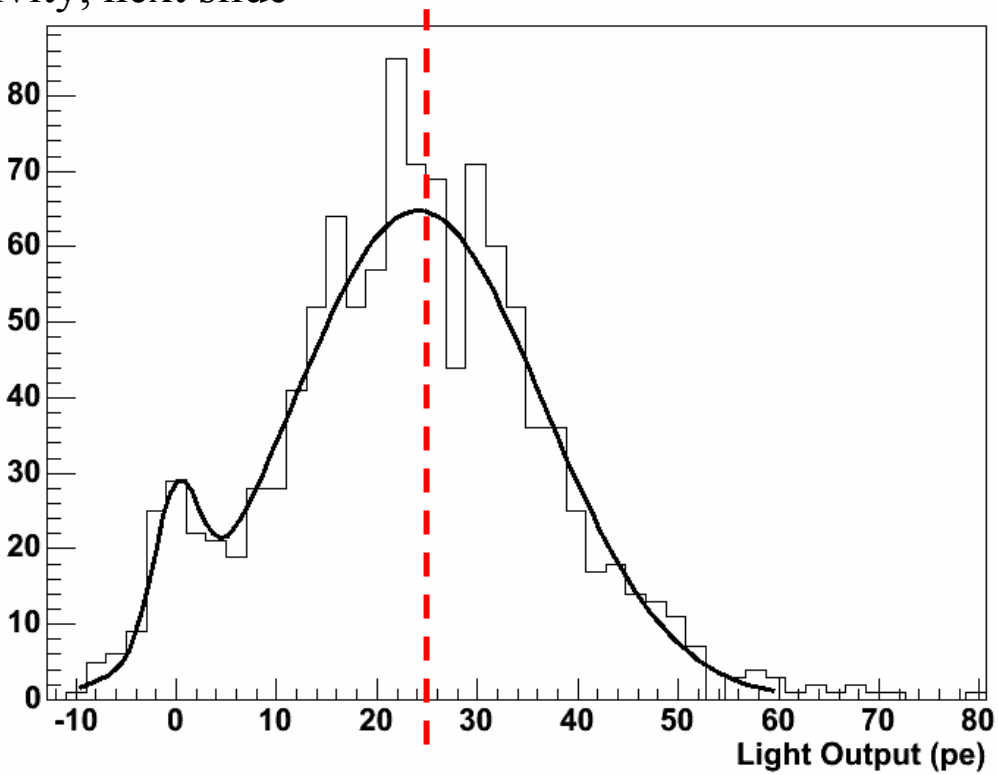
- **ES&H concerns are being investigated**
  - The major concern is not the structure, but that it forever contains the scintillator
  - See 3 NOνA notes, references on last page of this talk
  - Starting to write a Preliminary Safety Assessment Document
- **Required Approvals**
  - The state of Minnesota would only require the construction of buildings to have a Professional Engineer's stamp, not the contents of the building.
    - Our Project Engineer is an official Minnesota Professional Engineer
  - Normal Fermilab practice guided U of Minn for MINOS:
    - An engineering note for the structure is generated, perhaps with multiple authors.
    - This engineering note is reviewed in detail by a second engineer.
    - A "safety committee" then reviews the note.

"Question" #3:

Demonstrate the required 25 pe / MIP yield ASAP.

- **Done** (well, 24 pe anyway; expected 22.8 from this step) **! !**
  - **Used existing extrusions**
    to make a 6.0 cm deep cell (recall saw 13 pe at 2.2 cm deep)
    - still potential gains in reflectivity, next slide





The extrusion can be improved - 1

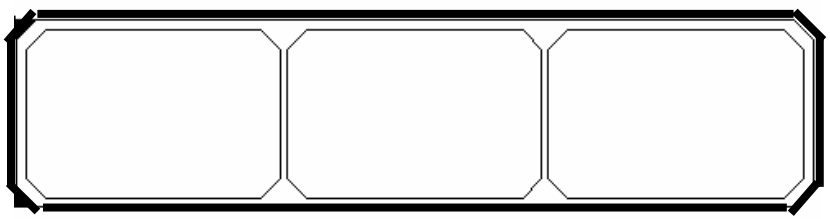
- 4 changes in composition, more TiO_2, run during week of June 13

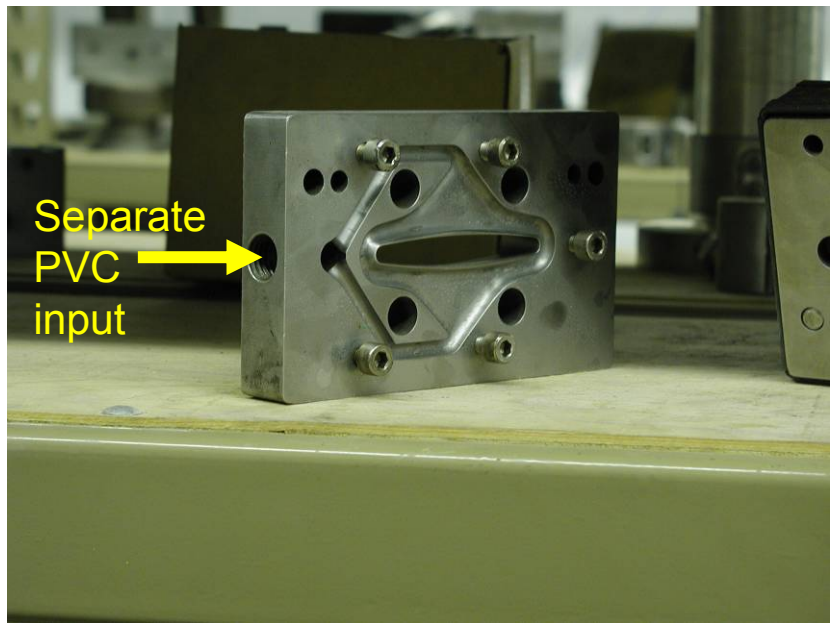
Sample with 25 pe				New samples being delivered, all but one with more TiO2										
				minimum extrudable PVC			just add TiO2			no fillers			no impact modifiers	
Component	phr	%		#1			#2			#3			#4	
PVC Resin	100.0	78.6%		100.0	96.9%		100.0	82.5%		100.0	78.6%		100.0	79.2%
TiO2 (many types, some "coated") These are all Kerr-McGee TRONOX CR-834	15.0	11.8%		-	0.0%		18.0	14.8%		19.0	14.9%		19.0	15.0%
Acrylic Impact Modifiers (there are many kinds)	5.0	3.9%		-	0.0%		-	0.0%		5.0	3.9%		-	0.0%
fillers (calcium carbonate in this mix)	4.0	3.1%		-	0.0%		-	0.0%		-	0.0%		4.0	3.2%
internal & external lubricants (unknown, many kinds)	1.0	0.8%		1.0	1.0%		1.0	0.8%		1.0	0.8%		1.0	0.8%
organo-tin stabilizers (3 major groups, maybe 20 types)	2.3	1.8%		2.3	2.2%		2.3	1.9%		2.3	1.8%		2.3	1.8%
Total	127.3			103.3			121.3			127.3			126.3	
				milky & translucent										

Will do chemical analysis at Argonne

The extrusion can be improved - 2

- Note we cover the extrusion with black plastic to keep out ambient light
- How do we do this in the experiment?
  - **Co-extrude black PVC ?**
    - Advantage of composite material, no ” joint”
    - Perhaps 0.3 mm thick
    - Add a part to the extrusion die





Issue #4 (a):

Perform a more detailed evaluation of the cosmic ray background.

Assess the need for an overburden.

- Cosmic ray muons
  - About 8 per 10 μsec spill
    - Incoming charged track cannot fake ν_e
    - Distributed, so not a problem for ν event recognition
      - On average μ tracks are 16 meters apart
      - Typical ν event is a few meters long
    - These μ are useful for calibration monitoring, median energy is 4 GeV

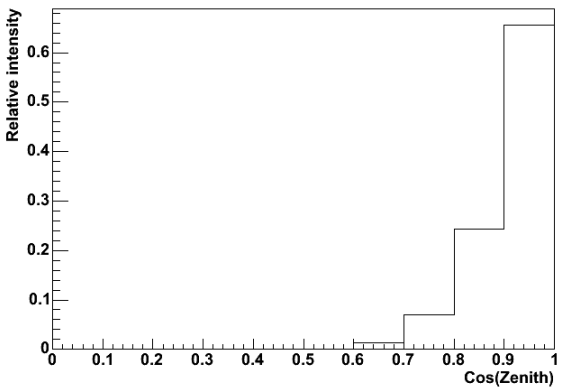
Issue #4 (a):

Perform a more detailed evaluation of the cosmic ray background.

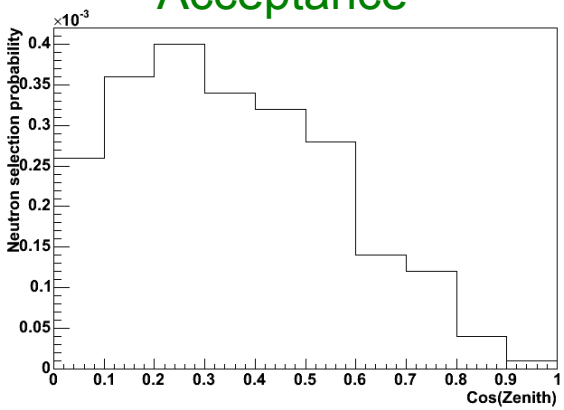
Assess the need for an overburden.

- **Neutrons, about 1 event every 100 spills with energy > 2 GeV**
  - More vertical than muons, average angle ~20^{o} from zenith
  - Median energy ~ 100-200 MeV
  - 1.5 GeV required to produce a single π @ 60^{o} which might fake an electron
    - Angular distribution of neutrons and produced π's do not typically point to Fermilab
    - Apply our selection criteria for ν_e events and find 0.3 events pass in 5 years of data

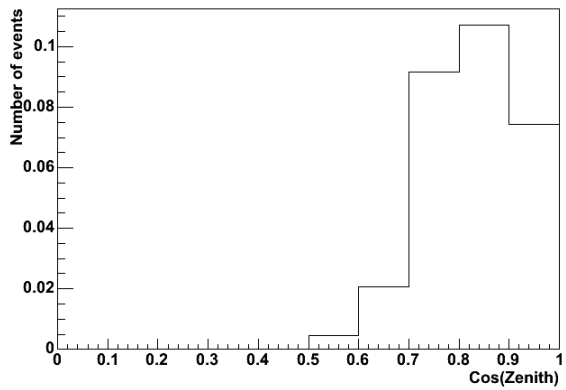
Neutron Flux



Acceptance



Convolution



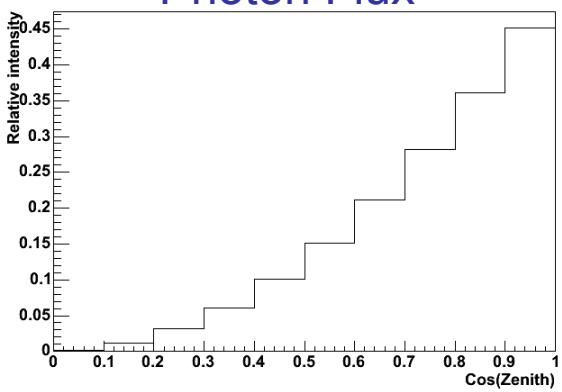
Issue #4 (a):

Perform a more detailed evaluation of the cosmic ray background.

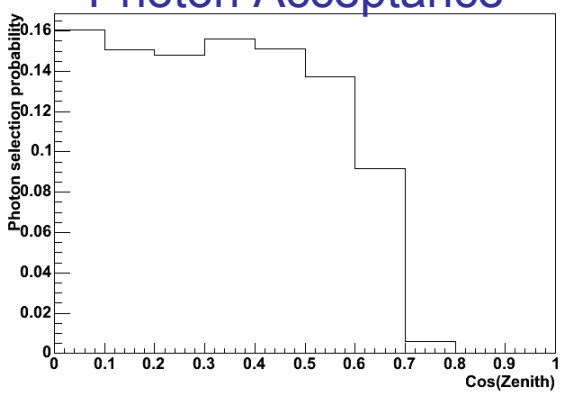
Assess the need for an overburden.

- **Electrons and Photons, about 4 per 10 μsec spill**
  - Most have energies below 100 MeV and shower in the top of the detector
  - Still worrying about high energy photons that may penetrate and fake a ν_e QE
    - 2500 events over a 5 year run
  - Additional handles not yet tried
    - angular distribution relative to Fermilab, cut harder
    - Impose transverse momentum conversation (not done in this particular analysis)
    - Only 2% > 1 GeV, usually accompanied by other particles -- can we see the other particles to reject these? (needs more simulation)
    - Most are e^+e^- conversions, so double pulse height at start may help
    - **Conservation solution is to put in an overburden**

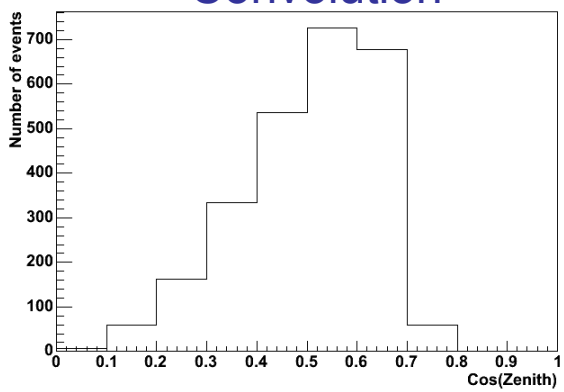
Photon Flux



Photon Acceptance

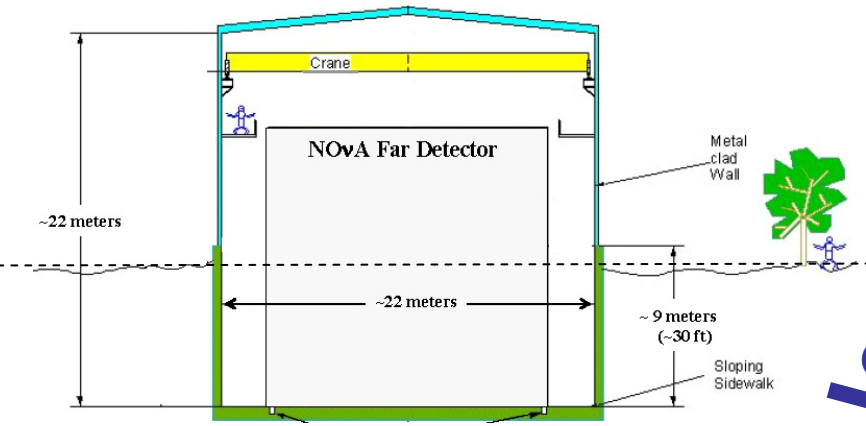


Convolution



3 m overburden is now our default plan

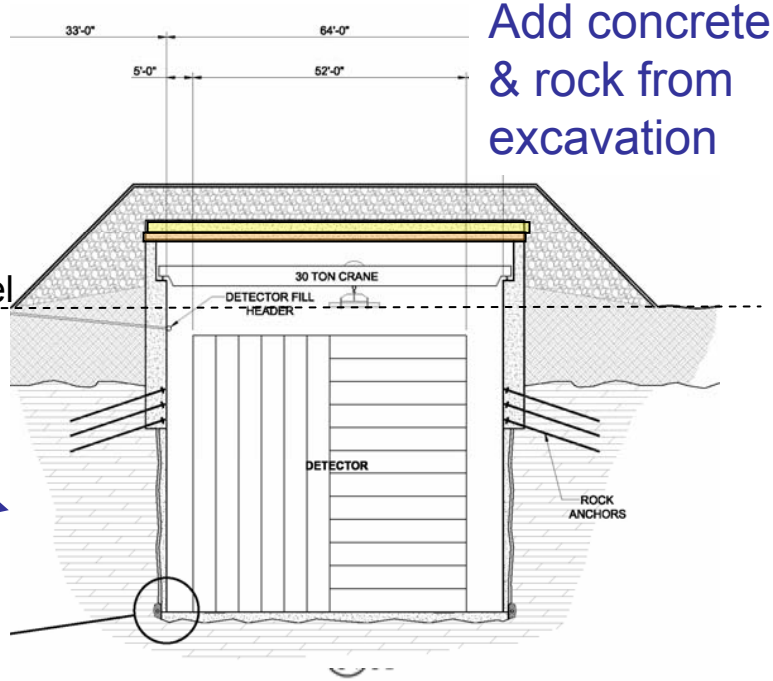
- The 2500 fake ν_e events from electron and photon cosmic rays can be attenuated to a few events (per 5 years of running) with an overburden of ~ 3 meters of rock.



Proposal Design

Go deeper

Add concrete & rock from excavation

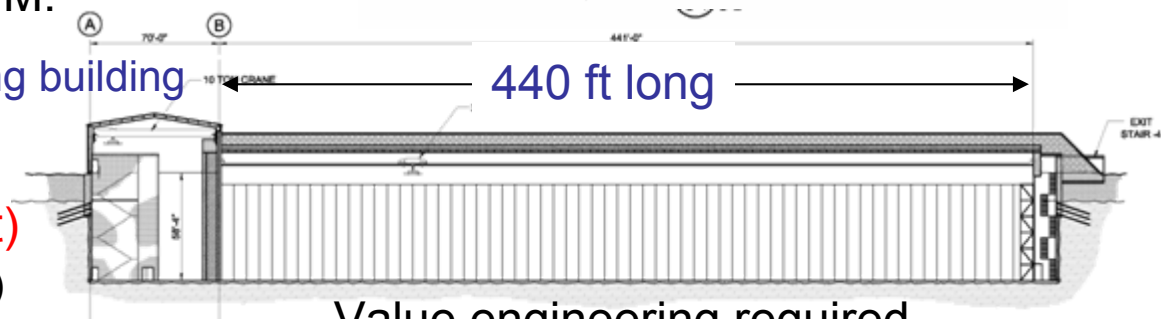


Cost differential to original $ 11.5 M:

+ $ 4.1 M excavation
+ $ 4.0 M overburden
- $ 2.6 M above ground bldg
- $? On HVAC (sod house effect)

< + 5.5 M or < 50% (< contingency)

It's a long building

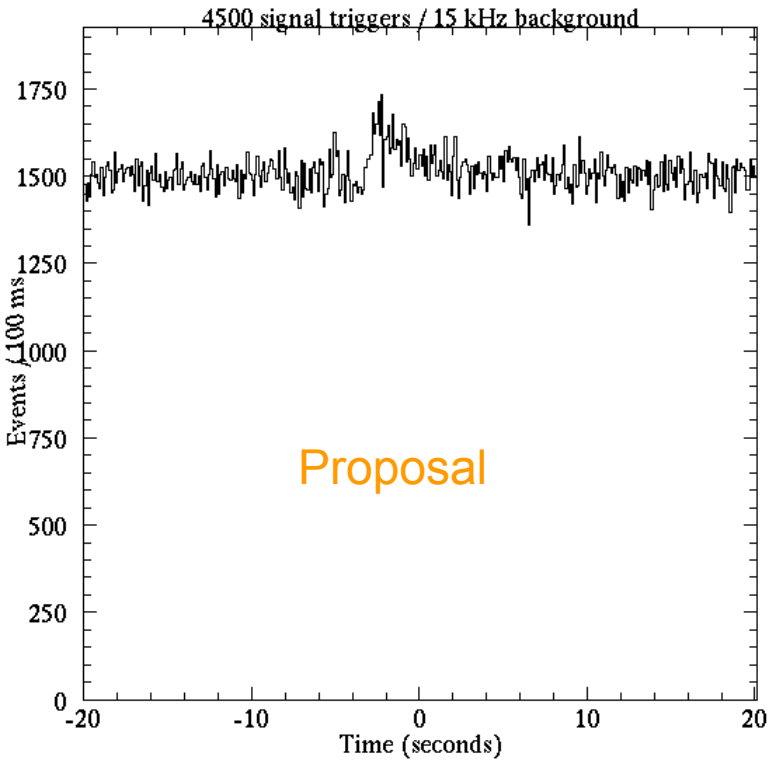


Value engineering required

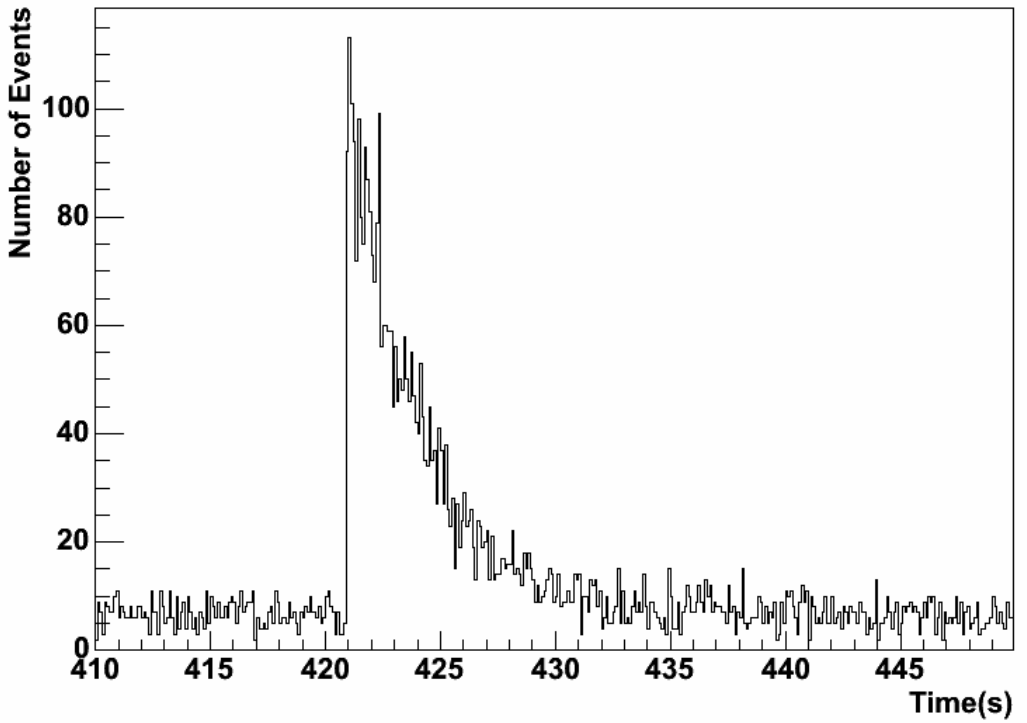
Overburden by-product

- Better shot at supernovas

Signal in 100 ms bins for a galactic supernova assuming a 3 m overburden



1500 signal events

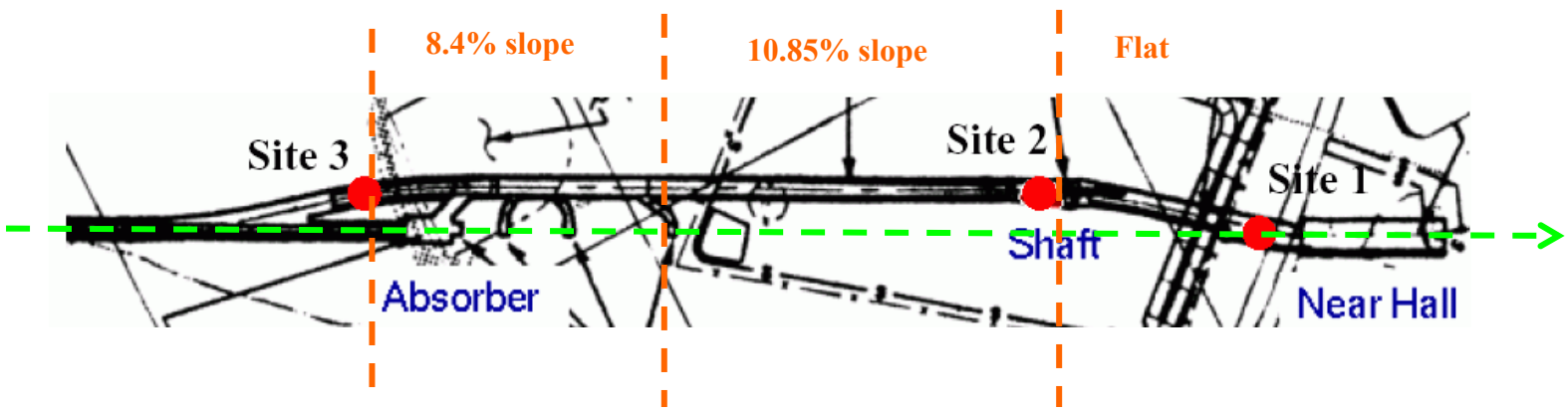


Issue #4 (b):

NOνA plans to minimize the mismatches between the ν spectra in the Near & Far detectors by taking data at various near sites, using MC to extrapolate to the far site

(i) **What are the practical implications of moving the Near Detector?**

- Pier has said "all hell will break loose if MiniBooNE confirms the LSND signal".
- In this ν spectra case, one "hell" would be the need to look at shorter baselines and that means moving the Near Detector upstream of the MINOS shaft
  - Then we are faced with moving 250 tons up an 11% slope
  - Might have to drain the Near Detector, move, refill
  - Looking forward to this fall's MiniBooNE result
    (of course this is actually very exciting if LSDN is confirmed)



Issue #4 (b):

NOνA plans to minimize the mismatches between the ν spectra in the Near & Far detectors by taking data at various near sites, using MC to extrapolate to the far site

(ii) How do MC predictions depend on MIPP & MINERνA?

- **No progress on this one**
- We need to generate ν spectra at several Near Detector underground positions with
  - ± 20% errors on π production (± 5% with MIPP)
  - ± 20% errors on ν cross sections (± 5% with MINERνA)
- Then turn the crank as outlined in the NOνA proposal to extract the various ν_e spectra contributions from
  - » Beam ν_e
  - » Fakes from NC
  - » Fakes from ν_μ
  - » Fakes from LSND signals
- Then find the error in our background extraction method (vs. known generated spectra) as a function of the input errors
  - Even the error in our extraction method with no generator errors is interesting
  - This is a big job and it will take a serious effort over many months
  - No one is working on it yet (candidates typically immersed in MINOS)

Encouragment #5:

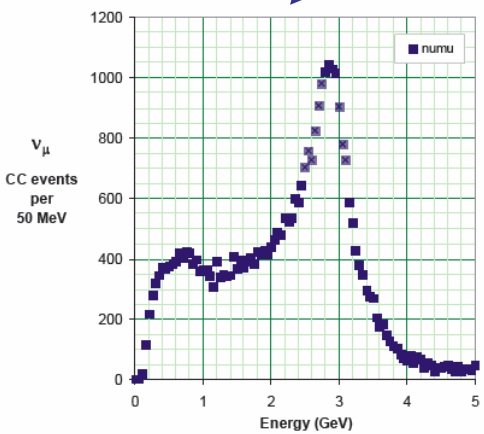
Perform more complete studies of the expected detector performance.
Address in particular the energy reconstruction accuracy as a function of the ν energy down to the lowest relevant energies

- **No progress yet**
- On our list is to do the following:
  - **Efficiency and Energy resolution vs. E and *y***
    - Separately for Quasi-Elastics,
      for resonance production (single π^{ch}, single π^0),
      and for DIS events
    - Motivation is increased ν_e efficiency,
      - what kind of events are we missing?, can we compensate somehow?
      - ~ 33% of events at 2 GeV are QE, yet our efficiency overall is only 24%
    - Relevant energies are 1 – few GeV if we are to understand the Near Detector beam spectra and the MINOS surface building data (next slide)
  - **Understand μ energy resolution**
    - Range or pulse height
    - See if Michel electron signal helps μ identification
  - **Understand the effect of our new larger cell size on proton recoil measurements (used for θ_{23} measurements)**

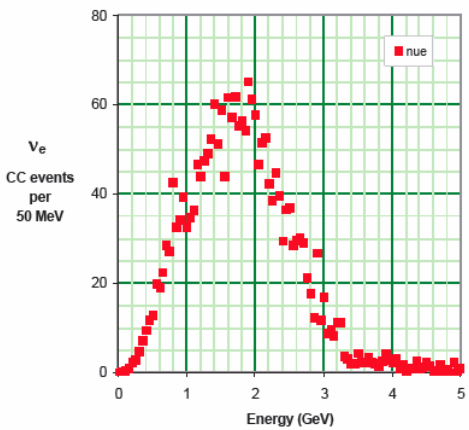
Encouragment #5:

Perform more complete studies of the expected detector performance.
Address in particular the energy reconstruction accuracy as a function of the ν energy down to the lowest relevant energies

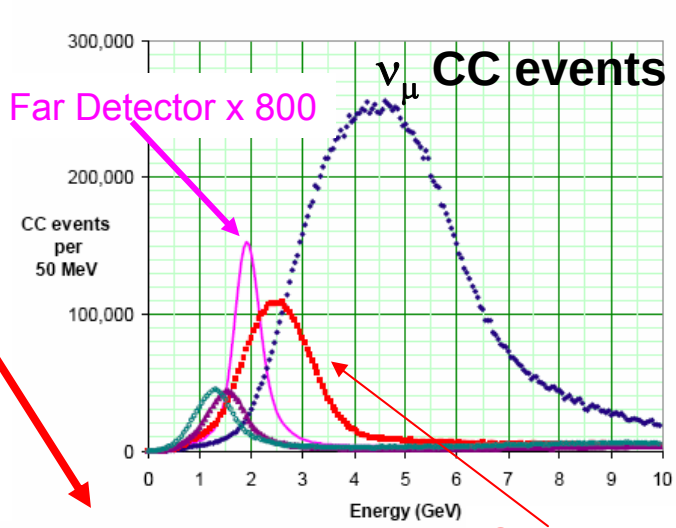
- **"Relevant Energies" = ~ 1 GeV to ~ few GeV**
  - **NuMI underground for Beam spectra**
  - **MINOS Surface Bldg**

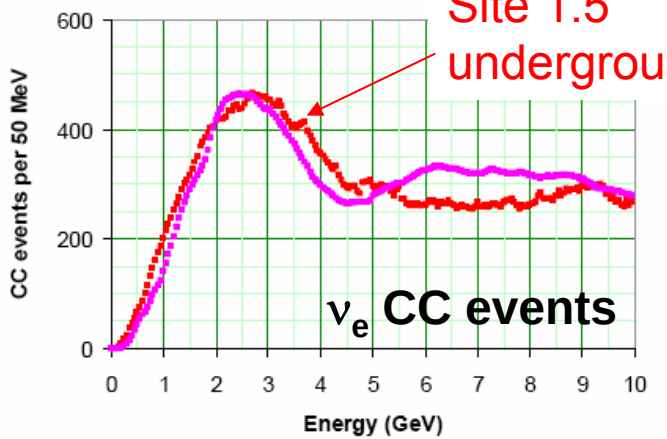


ν_μ CC events



ν_e CC events





Question #6:

How could the results of a "medium-scale" reactor ν experiment be used with results from NOνA , and from NOνA & T2K in order to improve the combined sensitivity?

How could the NOνA run program be adapted to provide the best combined sensitivity?

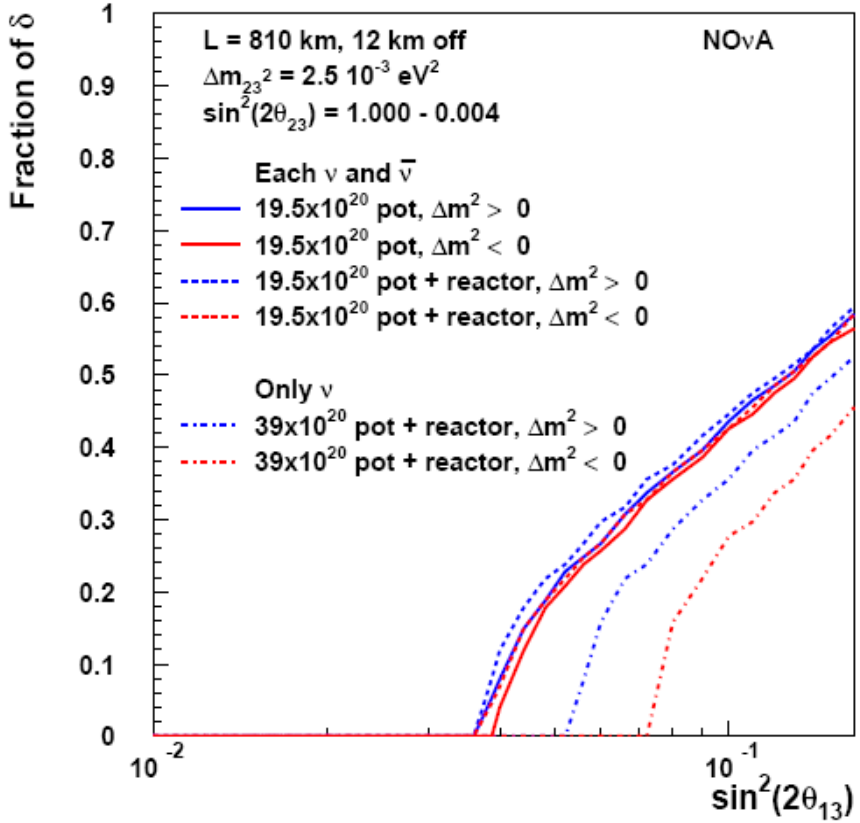
- There are two classes of reactor considered
  - a "Medium Reactor" as defined by the APS study with 90% CL sensitivity for $\sin^2(2\theta_{13}) = 0.01$
  - Braidwood, which is claiming 0.005 sensitivity at 90% CL

Mass Ordering: NOνA & Reactor

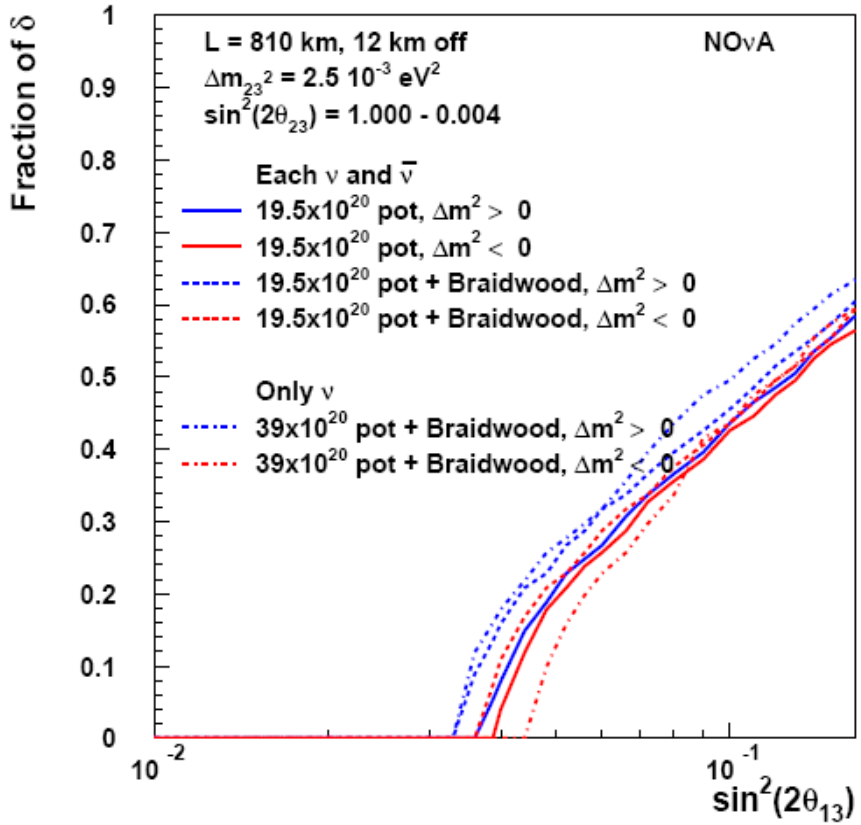
NOνA Alone 3 yrs ν + 3 yrs anti-ν
NOνA + Medium Reactor, 3+3
NOνA + Medium Reactor, 6 yr ν only

Same three scenarios,
NOνA with Braidwood

95% CL Resolution of the Mass Hierarchy



95% CL Resolution of the Mass Hierarchy



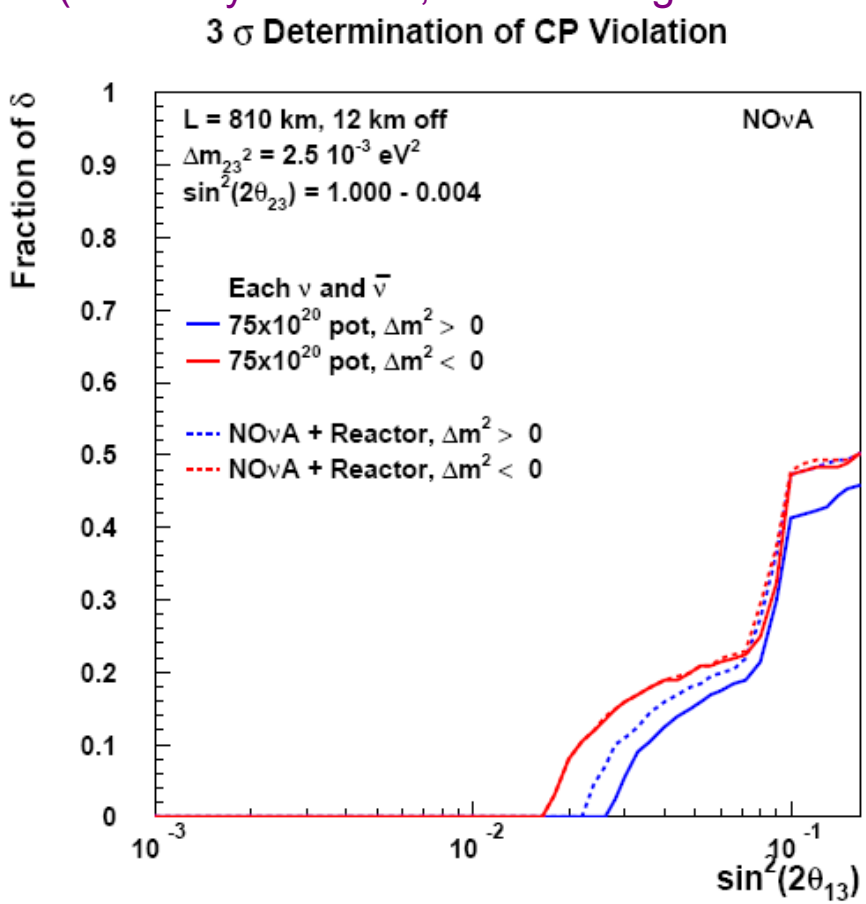
Medium reactor does not help very much
& 3rd scenario is a loser

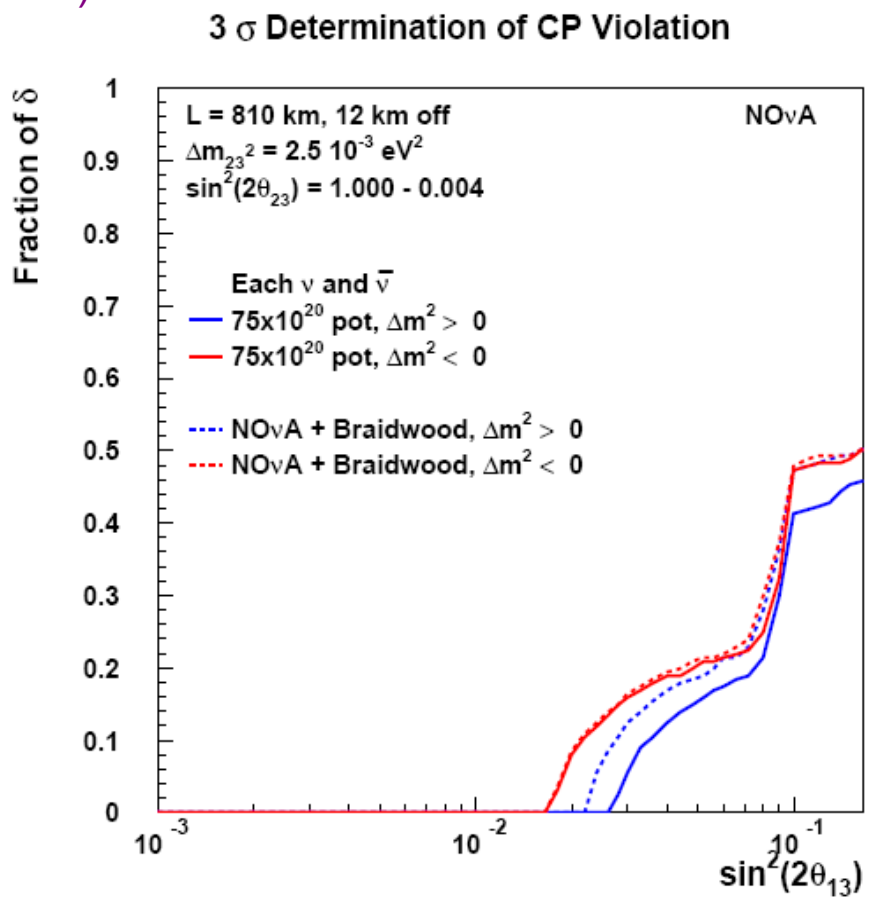
Braidwood helps a bit, but not optimum since lose independent measurements of mass order & CP, and lose ability to resolve θ_{23} ambiguity

CP violation: NOνA & Reactor

NOνA Alone 3 yrs ν + 3 yrs anti-ν
NOνA + Medium Reactor, 3+3
(no ν-only scenario, it does not get to the 3σ level)

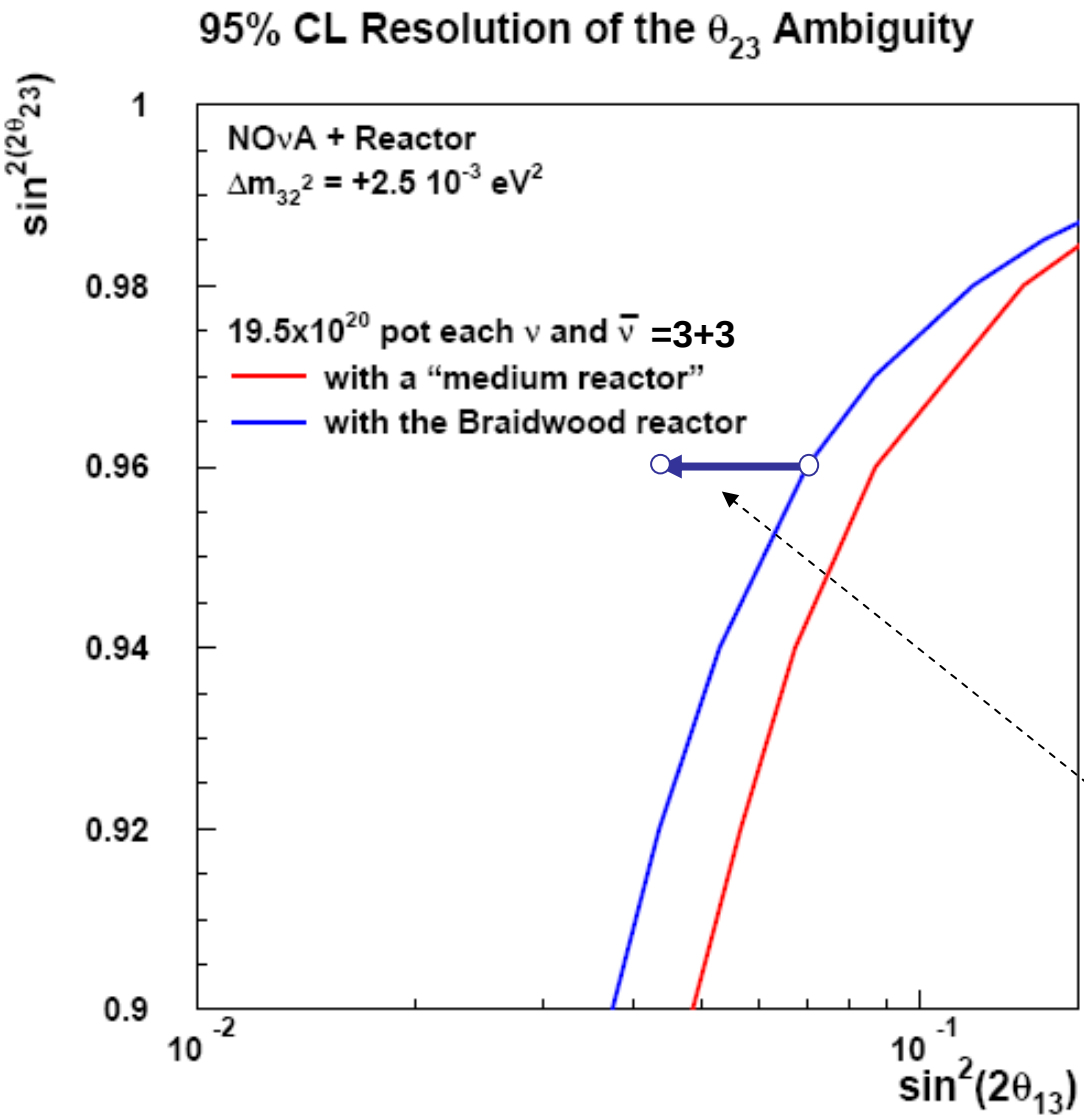
Same two scenarios,
NOνA with Braidwood





Neither reactor helps much, not too surprising
since these graphs are for NOνA with a Proton Driver

θ_{23} Ambiguity: NOνA & Reactor



Somewhat sensitive to δ, mass ordering, & the sign of the ambiguity.

But the sensitivities are not strong, so Gary averaged over them.

He also assumed θ_{23} itself is perfectly measured, so the curves are slightly optimistic.

One Braidwood point done with NOνA + Proton Driver, get substantial improvement

Question #7:

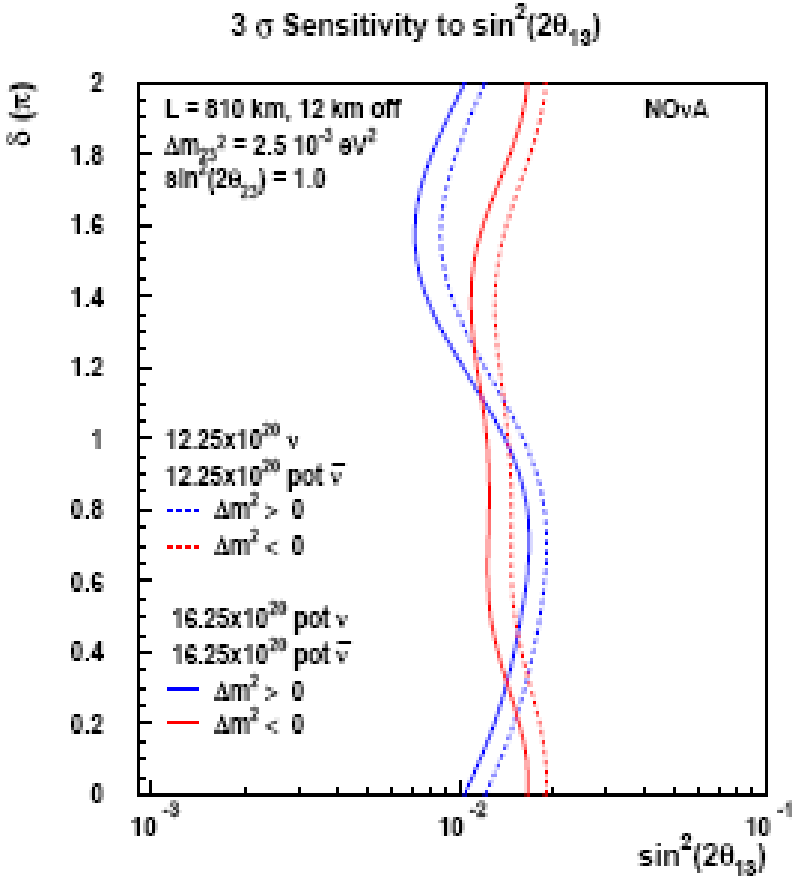
Please plot NOνA sensitivity for a more conservative flux of 4.9 x 10^{20}/year (vs. proposal at 6.5 x 10^{20}/year)

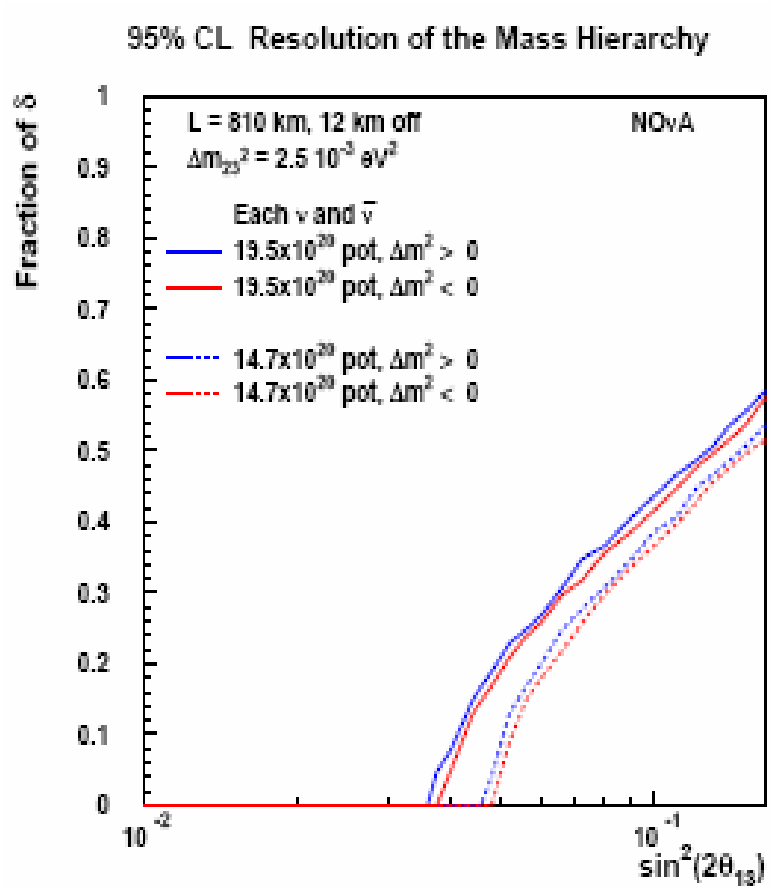
- The short answer is a factor of $(6.5/4.9)^{0.5}$ worse
  - That's 15%
  - OR, run (6.5/4.9) times as long,
    so 5 years → 6.6 years

- Long answer is the complete suite of plots, the next slide has two of them….

Question #7:

Please plot NOvA sensitivity for a more conservative flux of 4.9 x 10^{20}/year (vs. proposal at 6.5 x 10^{20}/year)

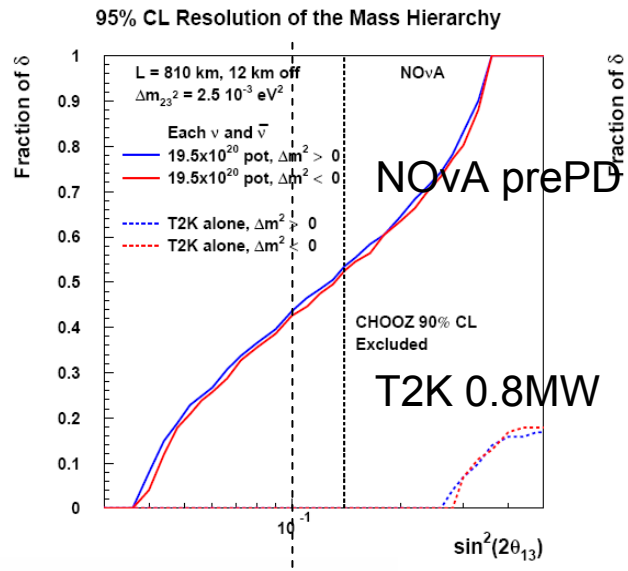




Question #8:

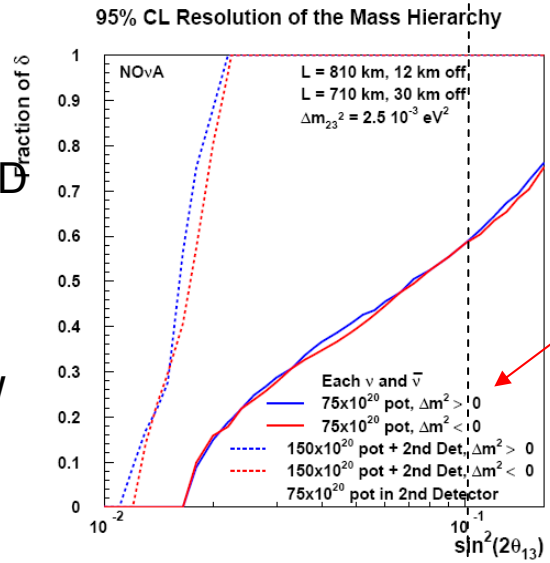
Please plot a direct comparison of the NOνA sensitivity in a Proton Driver era with a high-intensity JPARC program, with and without HyperK.

- Thought we had already done that one, but apparently only in 3 separate plots.
  - Here are the plots
- Slide # 5 shows remaining cases for mass hierarchy
- Slide #6 shows the comparison for CP violation

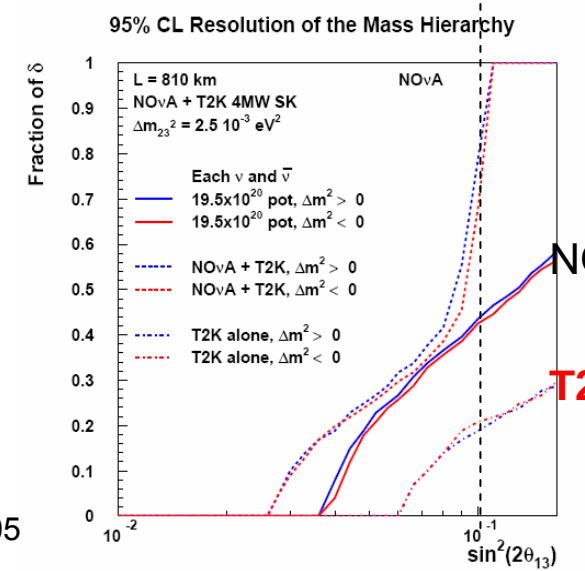


NOvA prePD

T2K 0.8MW

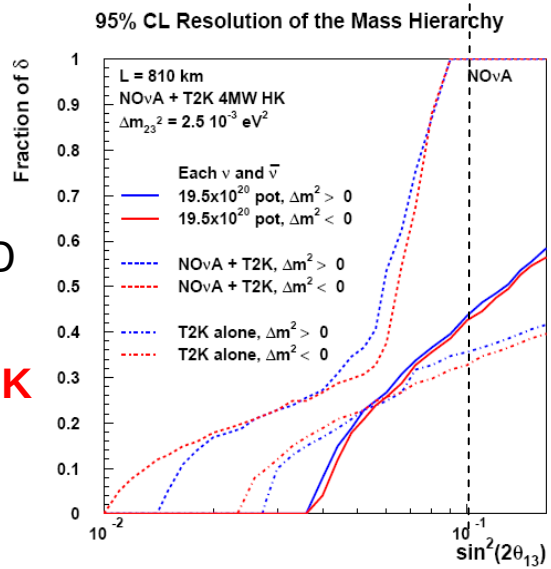


NOvA PD



NOvA prePD

T2K 4MW SK



NOvA prePD

T2K 4MW HK

Other Topics

Collaboration Building

- **Clearly we could use more people**
  - Have talked to
    - Representatives from India
    - Italian scientists
    - CERN physicists
      - Statement from CERN DG at Elba that some CERN scientists could participate in NOνA
    - BTeV people
    - Even some people currently on T2K
  - Our stock is up as people begin to realize that twice the beam of our original proposal (when the Tevatron Collider running stops) means this is the best experiment
    - But still reservations about whether the U.S. will really do it.
- **Within the original collaboration**
  - We are getting people to formally sign up for R&D tasks
    - We have a 30 page list of tasks to be completed in the next 3 years
  - We are getting support $ to people at universities and labs
    - ANL, Indiana, Minnesota, CalTech, Harvard

Project Team Building

- Project Manager – John Cooper
- Deputy Project Manager – Ron Ray
- Project Engineer – Dave Pushka
- Project Budget Officer – Suzanne Pacek
- Project Scheduler – Bill Freeman
- Schedule & documentation – Harry Ferguson
- Documentation – Dave Boehnlein
- Administrative support – Carol Angarola

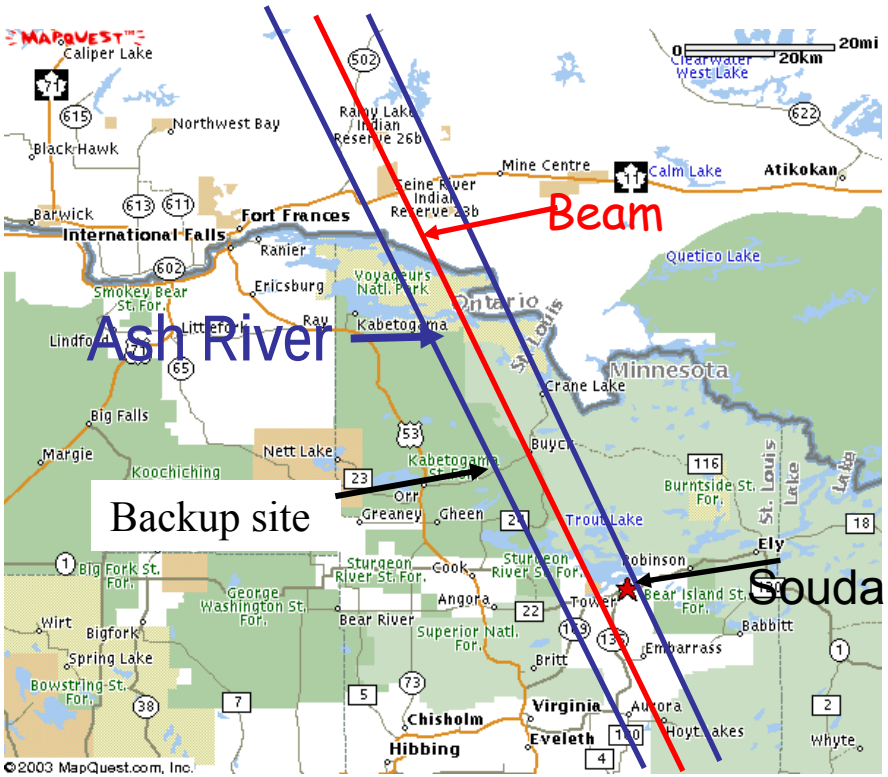
- Trying to find space to sit together
  - Currently spread over 3 floors – 8, 10, 12

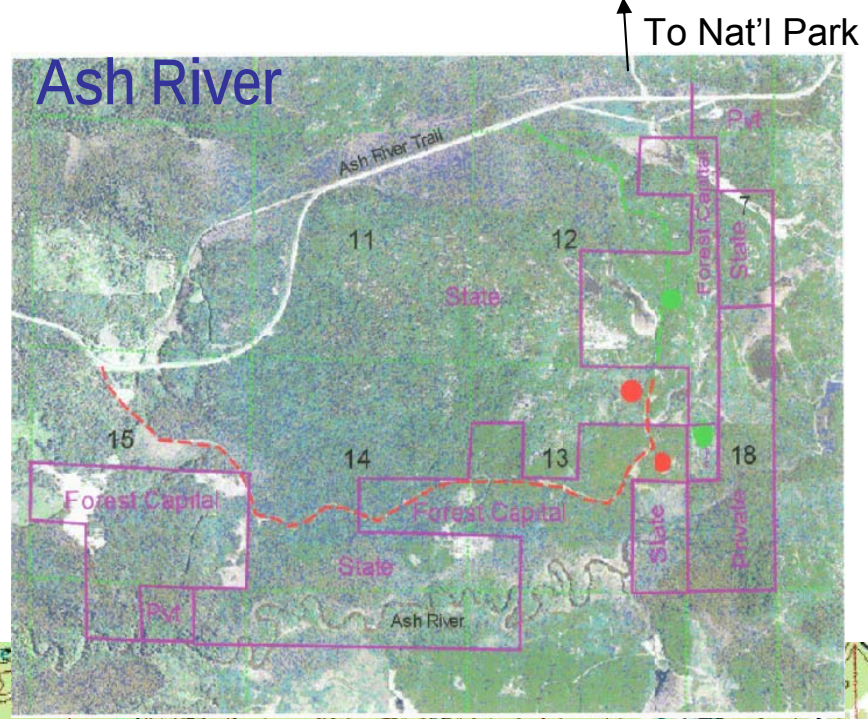
Project Office work list, short term

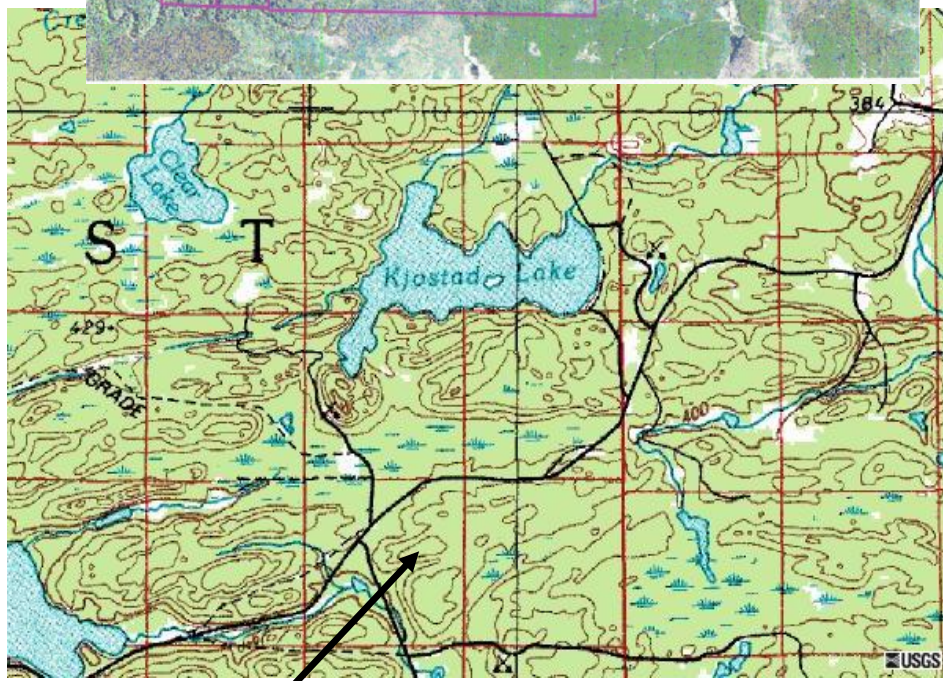
- Supporting connections made with Fermilab Resources: FESS, ES&H, BS, CD, PPD
  - e.g. CD collaborating on DAQ
- R&D Procurements this Fiscal Year
  - APD work with Hamamatsu on 32 channel device
  - Environmental studies of two sites (next slide)
- Working on the WBS,
  - (that's: Work Breakdown Structure)
  - Thinking to include simulation efforts here
    - » Gives it structure and organization, & somebody responsible
- Director's Review on July 18-20

Why Two Sites?

- Ash River (810 km)
  - power shortage, long access road
- Back-up Site at Orr/Buyck Road (775 km)
  - "probably" better power, clearly shorter access road
  - A few more people



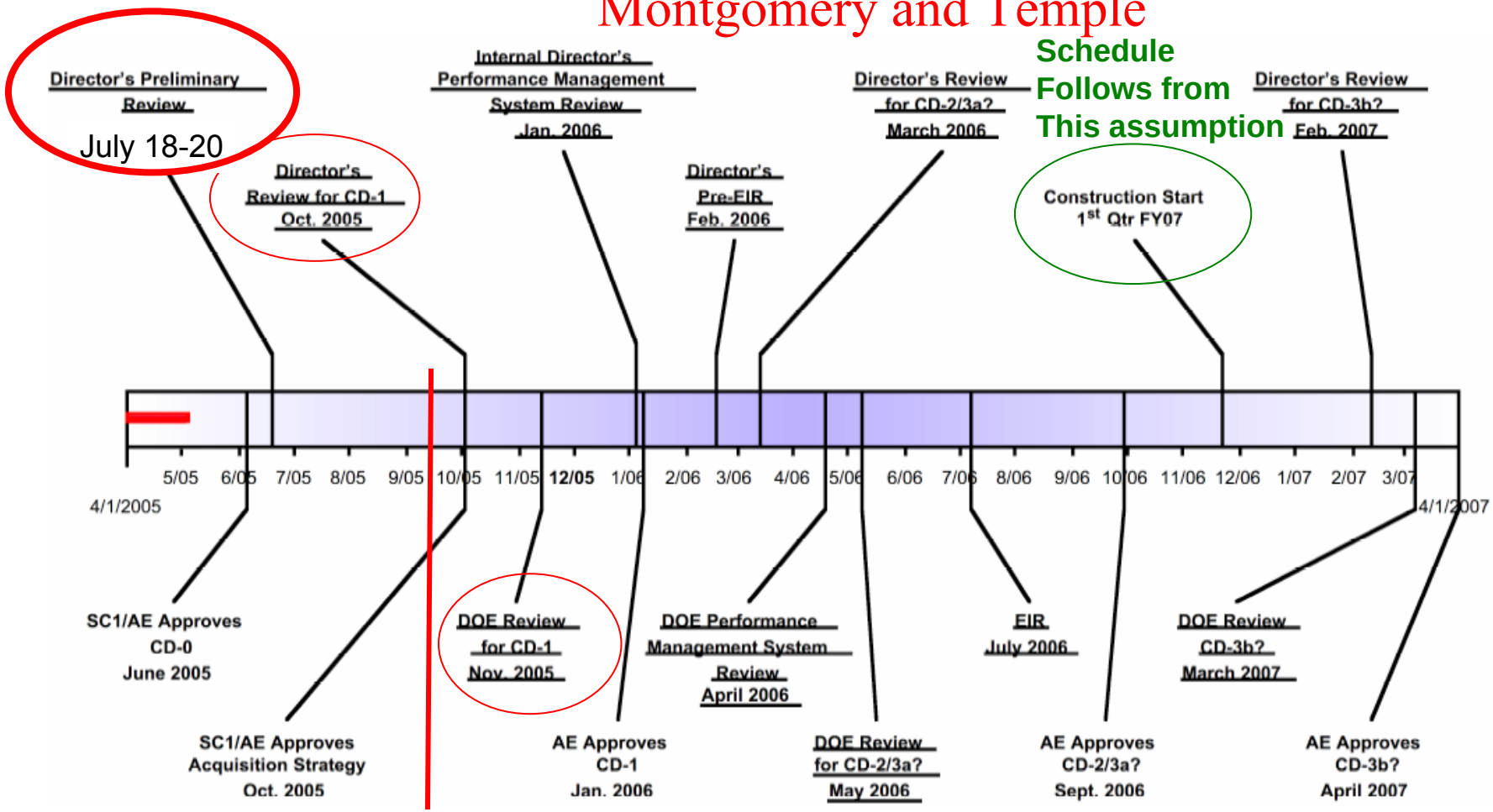




Backup Site: Orr-Buyck Road

The longer term Project tasks

NOvA Working Group Meetings
Montgomery and Temple



Need Conceptual Design Report,
Baseline Cost Range & Resource Loaded Schedule
Preliminary Safety Assessment Document,
preliminary Project Management Plan

Pointers to some documentation

- http://www-nova.fnal.gov/NOvA_Proposal/Revised_NOvA_Proposal.html
  - for the corrections to the plots in Chapter 13 of the proposal
- http://www-nova.fnal.gov/reports_page.html
  - For Gary's talks at EPP2010 and NuSAG
- http://home.fnal.gov/~jcooper/
  - For a compilation of up-to-date plots on mass hierarchy and CP
  - Look for "Updated MassCP_Collection"
- http://www-nova.fnal.gov/notes/notes.html
  - For the complete list of NOνA notes
    - Just click on the last bullet on this web page for the complete list of notes and you can get to each note by clicking on its note number
  - The 3 on ES&H are #57, 58, 59

Answers to PAC Questions to NOvA June 19

John Cooper

2005 Aspen PAC Meeting

----- Original Message -----

From: "Jeffrey A. Appel, 630-840-3922, MS 105" <appel@fnal.gov>

To: "John Cooper" <jcooper@fnal.gov>; "Gary Feldman" <feldman@physics.harvard.edu>

Cc: "Michael Witherell" <witherell@fnal.gov>; "Pier Oddone" <pjoddone@fnal.gov>; "Hugh Montgomery" <mont@fnal.gov>; "Andy Lankford" <ajlankfo@uci.edu>; "Boris Kayser" <boris@fnal.gov>; "Jackie Coleman" <jackiec@fnal.gov>

Sent: Sunday, June 19, 2005 10:19 AM

Subject: Questions from the PAC (fwd)

> John and Gary,
>
> Below are questions from the PAC subcommittee dealing with NOvA. We hope
> that you will be able to provide a response for the discussions this
> afternoon.
>
> Jeff
>
> Questions from the PAC
> For NOvA
>
> 1. For your analyses that entail both neutrino and antineutrino running, what assumptions are made concerning antineutrino production rates, cross sections in the detector, and neutrino backgrounds in the antineutrino beam?
>
> 2. In your discussion of the photoelectron yield for one minimum ionizing particle, what is the source of the inefficiency evident near zero light output, and why is the width of the distribution a large fraction of the mean?
>
> 3. Would your proposed short, pressurized prototype address all of the issues that a full prototype would address?
>
> 4. What is the difference in cost between the square and the organic structures? What are the implications of this difference for the overall detector cost?
>
> 5. What would be the advantages and disadvantages of simultaneous running of MINOS and NOvA for a few years, while MINOS completes its research program, and NOvA begins its own? Please consider physics issues, such as the ability to establish a rise in the muon neutrino survival probability as the neutrino energy descends through the first oscillation maximum. Please also consider the competition for resources, including neutrino flux and personnel. {This question is also being addressed to MINOS.}
>
> We recognize that your obtaining answers to questions 3 and 4 may require some time, but would appreciate responses to the other questions during the afternoon of June 19 if at all possible.

1. For your analyses that entail both neutrino and antineutrino running, what assumptions are made concerning antineutrino production rates, cross sections in the detector, and neutrino backgrounds in the antineutrino beam?

- Antineutrino production rates come from the standard beam package used by MINOS and NOvA (Mark Messier, Indiana), see next slide
  - Reversed horn polarity
  - Medium energy beam
  - Negative pion production
- Cross sections in detector see second slide

From the LOI

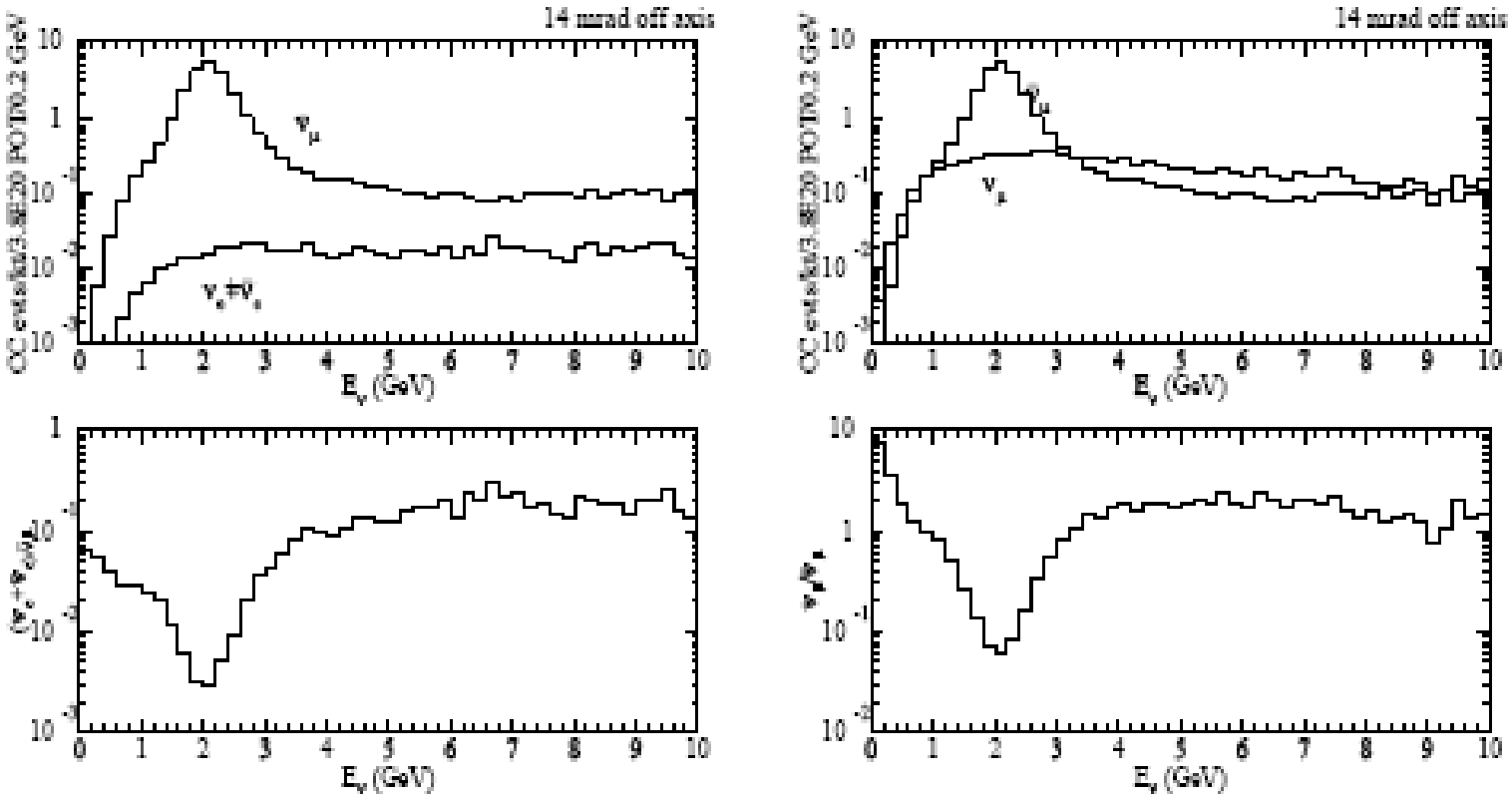


Figure 4.10: Composition of the off-axis antineutrino beam, medium energy beam configuration. Left shows the electron neutrino component. Right shows the wrong-sign muon component.

From the LOI

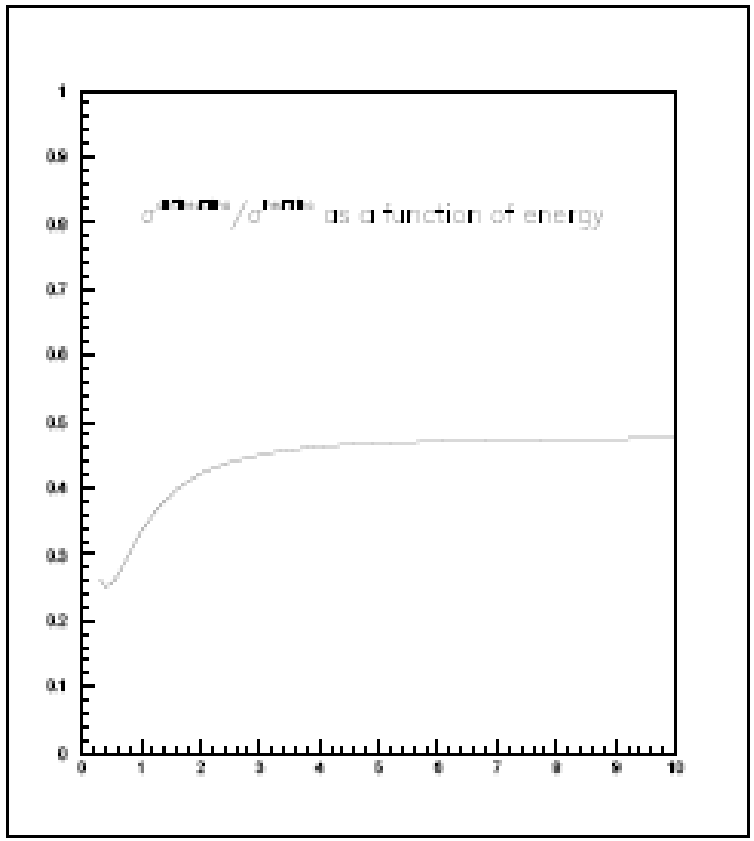


Figure 4.11: Ratio of antineutrino and neutrino CC cross sections as a function the the neutrino energy

Neutrino backgrounds in analysis

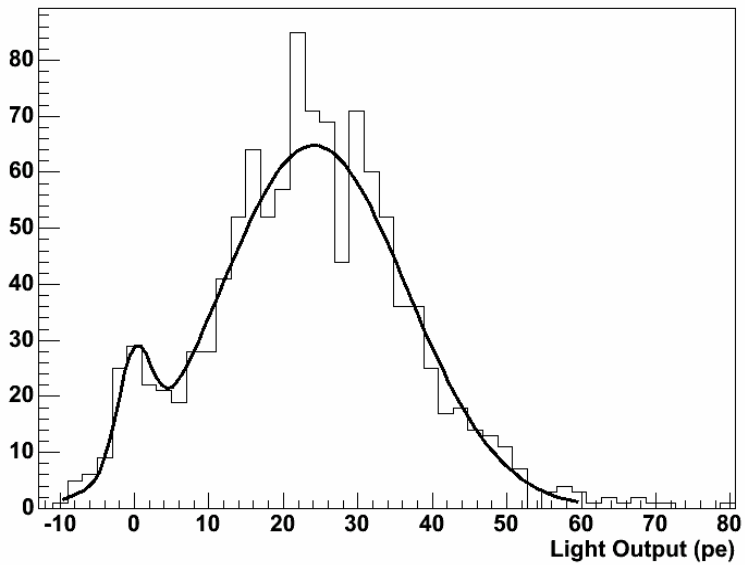
- Just added to the signal
  - This is OK for electron neutrino appearance search
  - For mass hierarchy it is not and the neutrino signals should be treated as a background for the antineutrino analysis (not done so far)

2. In your discussion of the photoelectron yield for one minimum ionizing particle, what is the source of the inefficiency evident near zero light output, and why is the width of the distribution a large fraction of the mean?

This is triggered on cosmics,
So inefficiency is likely due to
The triggering

Unable to reach expert on width,
Looks like more noise than
We advertise
350 electrons = 3.5 pe sigma,
This is more like 13 pe sigma
(might also be triggering, path length
Of cosmics in the larger cell?)

We will have to tell you later…..

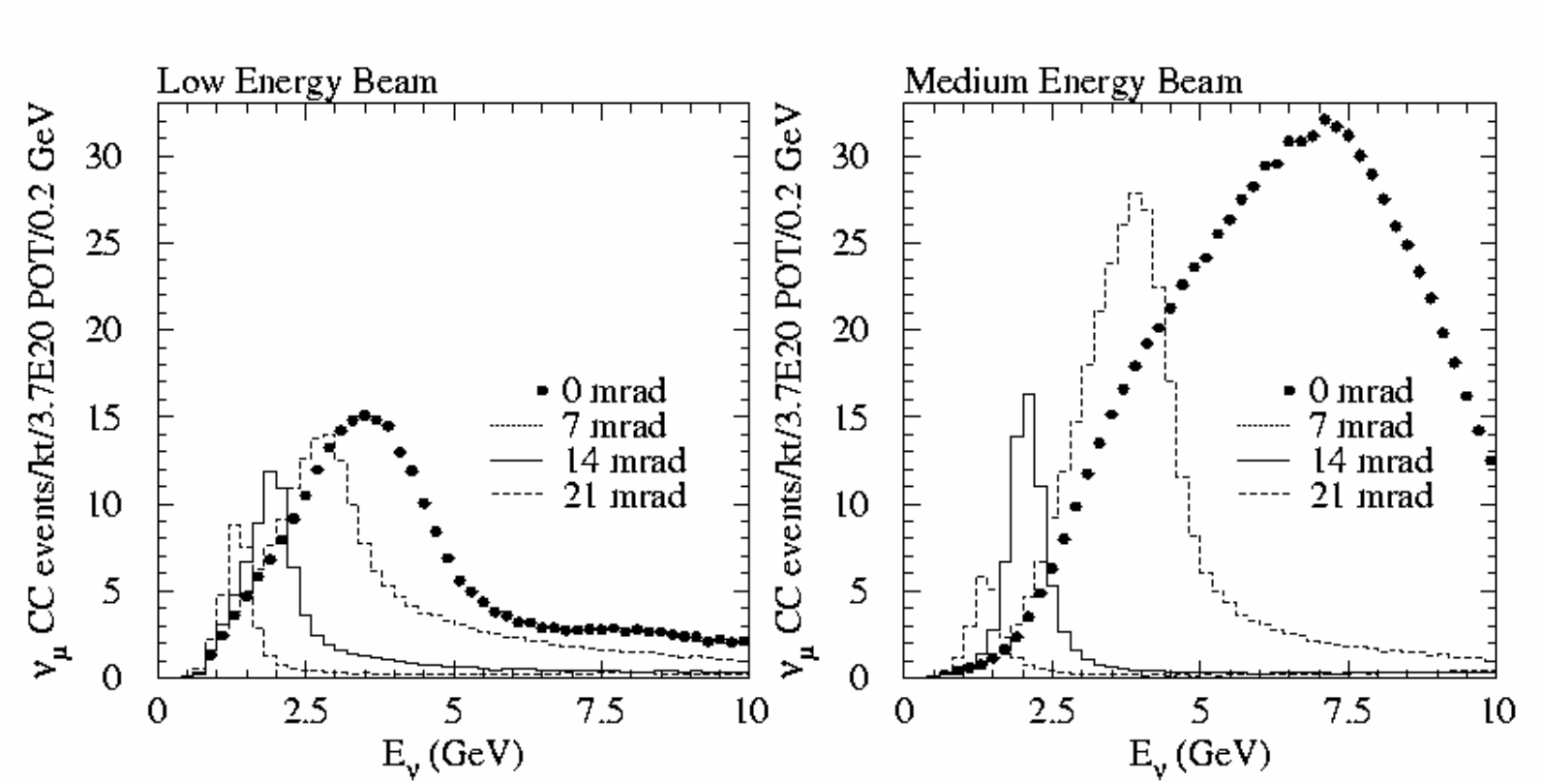


5. What would be the advantages and disadvantages of simultaneous running of MINOS and NOvA for a few years, while MINOS completes its research program, and NOvA begins its own? Please consider physics issues, such as the ability to establish a rise in the muon neutrino survival probability as the neutrino energy descends through the first oscillation maximum.

Please also consider the competition for resources, including neutrino flux and personnel. {This question is also being addressed to MINOS.}

flux

- Off axis event rates are almost the same for the Low Energy(MINOS) and Medium Energy(NOvA) configurations, so incompatibility is small and we could run together



personnel

- Mine crew separate from NOvA crew anyway since the construction has to overlap the MINOS operations in any case

- Scientific peronnel, same old problem
  - 67% of NOvA people are on MINOS….
  - More collaborators should start to change this ratio

science

- Gary: “most issues are best addressed by NOvA”
  - NOvA may even see the rise in muon neutrino survival probability as the energy sweeps down through the oscillation max better than MINOS
  - One new thought (at Ely this last week) is to look at MINOS ν_e appearance in the same manner as in NOvA
    - MINOS energy shape is very different, 3 – 5 GeV vs. 2
    - This means MINOS may be sensitive to the sign of the cos(δ) term and might add information
    - Even if MINOS has to use the ME beam

$P(\nu_\mu \rightarrow \nu_e)$ (in Vacuum)

- $P(\nu_\mu \rightarrow \nu_e) = P_1 + P_2 + P_3 + P_4$
  - $P_1 = \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2(1.27\ \Delta m_{13}^2\ L/E)$ — "Atmospheric"
  - $P_2 = \cos^2(\theta_{23}) \sin^2(2\theta_{12}) \sin^2(1.27\ \Delta m_{12}^2\ L/E)$ — "Solar"
  - $P_3 = \mp J \sin(\delta) \sin(1.27\ \Delta m_{13}^2\ L/E)$
  - $P_4 = J \cos(\delta) \cos(1.27\ \Delta m_{13}^2\ L/E)$

  } Atmospheric-solar interference

where $J = \cos(\theta_{13}) \sin(2\theta_{12}) \sin(2\theta_{13}) \sin(2\theta_{23})$ x

$\sin(1.27\ \Delta m_{13}^2\ L/E) \sin(1.27\ \Delta m_{12}^2\ L/E)$

- When calculated, Gary gets a 1% effect in MINOS, so
  - Not clear MINOS is sensitive enough
  - May only work if $\sin^2(2\theta_{13})$ is large,
    - Perhaps in the range 0.05 – 0.10

$P(\nu_\mu \rightarrow \nu_e)$ (in Matter)

- In matter at oscillation maximum, P_1 will be approximately multiplied by $(1 \pm 2E/E_R)$ and P_3 and P_4 will be approximately multiplied by $(1 \pm E/E_R)$, where the top sign is for neutrinos with normal mass hierarchy and antineutrinos with inverted mass hierarchy.

$$E_R = \frac{\Delta m^2_{13}}{2\sqrt{2} G_F \rho_e} \approx 11\,\text{GeV}$$ for the earth's crust.

About a ±30% effect for NuMI, but only a ±11% effect for JPARC .

However, the effect is reduced for energies above the oscillation maximum and increased for energies below.